TECHNICAL MEMORANDUM

SUPPLEMENTAL WATER USE IN THE EVERGLADES AGRICULTURAL AREA 1970 - 1987

by

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January 1992

Water Resources Engineering
Department of Research and Evaluation
South Florida Water Management District
West Palm Beach, Florida

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EXECUTIVE SUMMARY

The Everglades Agricultural Area (EAA) is located south and east of Lake Okeechobee. It comprises approximately 1,100 square miles of predominately organic soils utilized primarily for agricultural production. The average annual irrigation demand for this basin is approximately 400,000 acre-feet, the majority of which is withdrawn from Lake Okeechobee.

The objective of this study is to evaluate the current criteria for water use allocation permits, thereby assisting the South Florida Water Management District's (SFWMD) Department of Regulation. The current water use allocation criteria is based on theoretical crop water use and effective rainfall.

In this study, the irrigation requirement predicted from theoretical crop water use and effective rainfall is compared to the applied irrigation based on historical structure flow data. This analysis represents an extension of Supplemental Water Use in the Everglades Agricultural Area, a SFWMD technical publication written by Mierau in 1974. Conclusions are drawn for the study period of 1970-1987 and comparisons are made to Mierau's observations for the period 1962-1972.

Basin evapotranspiration was estimated using the pan evaporation method. Two estimates of effective rainfall were used to represent upper and lower bounds for the actual effective rainfall. The upper bound was assumed to be equal to the area's total rainfall; the lower bound was assumed to be equal to the depth predicted by the effective rainfall formula presented in the USDA Soil Conservation Service's (SCS)

Technical Release No. 21. Mierau (1974) assumed total rainfall to be as effective. The current water use allocation criteria is based on the SCS equation.

The findings of this study are in general agreement with those reported by Mierau (1974). The conclusions are summarized as follows:

1. During dry seasons with below normal rainfall, the volume of applied irrigation was generally less than that theoretically required. Mierau (1974) reported a similar trend.
2. During dry seasons with above normal rainfall, the volume of applied irrigation was generally greater than that theoretically required if the basin's total rainfall was assumed as effective. Mierau (1974) reported a similar trend. Using the SCS effective rainfall formula, however, the applied irrigation was less than that theoretically required during all of the 1970-1987 dry seasons with above normal rainfall.
3. In general, the EAA, on an areawide basis, has not applied irrigation in excess of the District's permitted water use allocation for agricultural irrigation. Mierau (1974) reported a similar finding during 1962-1972.
4. Prior to 1979, the volume of drainage water pumped from the EAA to Lake Okeechobee was approximately equal to the volume of irrigation water released from Lake Okeechobee to the EAA. Mierau observed a similar trend during 1961-1972. Since 1979, due to the Interim Action Plan, the volume of drainage water pumped to Lake Okeechobee is less than that released to the EAA for irrigation.

NOTE: This technical memorandum has been edited by Wossenu Abtew, after the author left the District.

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INTRODUCTION

The Everglades Agricultural Area (EAA) is an area of approximately 1,100 square miles located south and east of Lake Okeechobee in western Palm Beach, eastern Hendry, and southeastern Glades counties. It is an area of extensive agricultural production and intensive water management. Regional water control is administered by the South Florida Water Management District (District) and the U. S. Army Corps of Engineers (Corps), and is accomplished by the Central and Southern Florida Project for Flood Control and Other Purposes (Project) levees, canals, and structures which encompass the basin.

The EAA is served by four Project canals: the Miami Canal, the North New River Canal, the Hillsboro Canal, and the West Palm Beach Canal. These canals were designed for flood control and water supply purposes. The Bolles and Cross canals interconnect the Project canals; however, structures and the canal cross sections limit the interconnecting flow.

This analysis was performed to provide assistance to the District's Regulation Department with the evaluation of the present agricultural water use allocation permit criteria. This analysis represents an extension of Supplemental Water Use in the Everglades Agricultural Area, a study performed by Mierau in 1974. Its objective is to compare applied irrigation, based on historical flow data, with the irrigation requirement based on estimated crop water use and effective rainfall.

The area of interest (Figure 1) is that part of the EAA which obtains irrigation water from Lake Okeechobee via the Project canals; the areas withdrawing water directly from Lake Okeechobee were excluded in this analysis. The area of interest will be referred to as the EAA study area.

Based on his analysis, Mierau (1974) listed four observations for the period 1962-1972:

1. During dry seasons (November-May) with below normal rainfall, supplemental water was applied at rates less than the estimated crop water requirement.

2. During dry seasons with above normal rainfall, supplemental water was applied at rates generally greater than the estimated crop water requirement.

3. Maximum monthly supplemental water application rates were substantially below the District's allocated rate for water withdrawal.
4. Cumulative supplemental water releases from Lake Okeechobee into the EAA were approximately equal to cumulative drainage water pumped from the EAA into Lake Okeechobee.

In this analysis, the period 1970-1987 is studied to determine if the observations listed above persist. Conclusions are drawn based on the period 1970-1987, and by including Mierau's data on the period 1962-1987.

NOTE: **This document precedes "Water Budget Analysis for the Everglades Agricultural Ares 1979-1990" scheduled for publication in early 1992.**

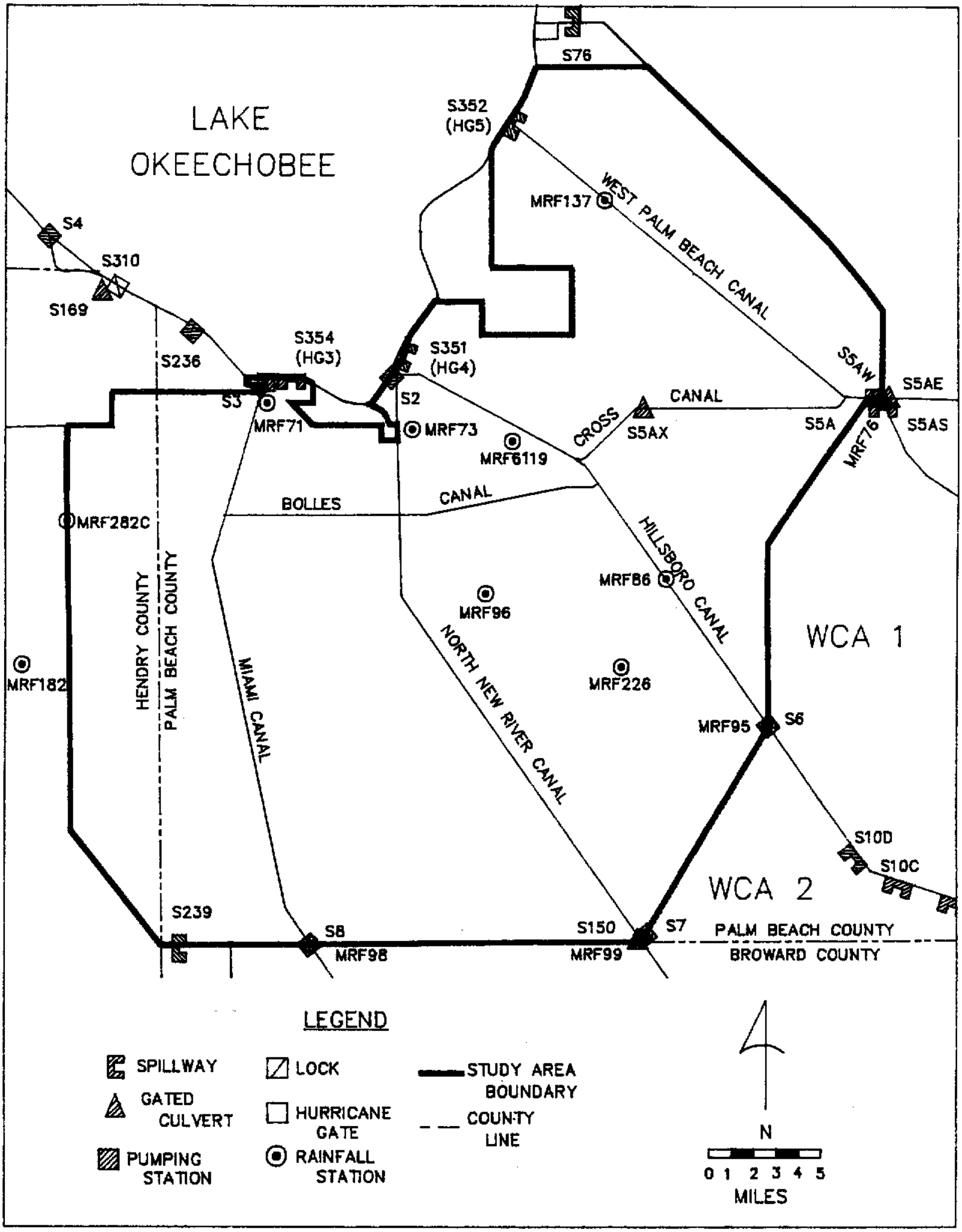

FIGURE 1. LOCATION MAP

MATERIALS AND METHODS

Data

Flow

Flow data represent the net daily flow through each District operated structure located on the boundary of the EAA. The flow gauging stations (Figure 1) are located near S-354 (replacement structure for HGS-3), S-351 (replacement structure for HGS-4), S-352 (replacement structure for HGS-5), S-2, S-3, S-6, S-7, S-8, S-150, and the S-5A complex. The flow through a structure configuration consisting of a pump station alongside a hurricane gate was defined as the combined flow through both structures. The combined flow at S-2 and S-351 (HGS-4) was measured north of the junction of the Hillsboro Canal and the North New River Canal.

Rainfall

Daily basin precipitation was estimated using the Thiessen polygon method and represents the weighted average of 13 rainfall stations distributed over the EAA (Figure 1). The daily Thiessen weighted values were summed to produce monthly precipitation estimates. In this analysis, the data at MRF 137 were preprocessed and represent the arithmetic average of stations MRF 137, MRF 138, MRF 58, and MRF 57. These stations are all located in the northwestern half of the S-5A basin. MRF 71C data were combined with the data at MRF 71, the former recorder being replaced by the latter during the beginning of 1974. MRF 282C (period of record 9/1/82 to present) was combined with the record at MRF 80 (period of record 10/16/57 to 10/31/82); these stations are approximately 1.3 miles apart.

Pan Evaporation

Daily basin pan evaporation was estimated using the Thiessen polygon method and represents the weighted average of four class A evaporation pans. The evaporation pan stations are located at Clewiston, S-5A, S-7, and the Agricultural Experiment Station at Belle Glade. Missing values were estimated if the length of missing records did not exceed approximately one week. Estimates were based on a linear interpolation between the recorded values. The S-7 pan evaporation data prior to 1985 were not used. Prior to 1985, this evaporation pan used a float-pulley recorder; this type of recorder was found to be inaccurate for recording pan evaporation data. Since 1984, manual readings have been taken at S-7. The daily Thiessen weighted pan evaporation values were summed to produce monthly estimates.

Land Use

Three agricultural land use categories were studied: sugarcane, vegetables, and improved pasture/sod. Urban land use, unimproved pasture, and wetlands were not included in the study because they represent a small percentage of the total supplemental water use in the study area.

Land use estimates for 1970, 1971, and 1972 were taken from Mierau's report (1974). Land use estimates for 1979 and 1988 were supplied by Geographic Sciences Division, Technical Services Department, from the ComputerVision database. These values were subsequently modified based on land use information contained in the District's permit files, sugarcane production estimates supplied by the Florida Sugar

Cane League, production estimates contained in the Florida Agricultural Statistics bulletins for Vegetables and for Field Crops, and discussions with District personnel.

Land use estimates were linearly interpolated for the intervening years (1973-1978 and 1980-1987). The Florida Agricultural Statistics bulletins for Vegetables and for Field Crops, as well as the Florida Sugar Cane League production estimates, were available for each year of the period studied. These data were not used for the intervening years, because they do not differentiate between that part of the EAA which withdraws water from the Project canals from the part which withdraws water directly from Lake Okeechobee. The linearly interpolated land use estimates for sugarcane were compared to the published data; they followed a similar trend with respect to the rate of change of agricultural land use over time. Table 1 lists the land use data for sugarcane, vegetables, and pasture/sod.

Table 1. Land Use

Year	Sugarcane (acres)	Vegetables (acres)	Pasture / Sod (acres)	Total (acres)
1970	192,000	80,000	128,000	400,000
1971	208,000	77,000	126,000	411,000
1972	256,000	83,000	125,000	464,000
1979	297,000	68,000	63,000	428,000
1988	365,000	48,000	33,000	446,000

Methodology

Applied Irrigation

Applied irrigation (supplemental water) is defined as the net water released into the EAA via the Project canals which was not discharged through the downstream end of the respective canal during the same day. Applied irrigation consisted of water released through the hurricane gates from Lake Okeechobee as well as water entering from the Water Conservation Areas (WCAs) by gravity flow or siphoning. Daily flow volumes were summed for each month and converted to an equivalent depth over the irrigated acreage.

Evapotranspiration

Evapotranspiration (ET) was estimated on a monthly basis using the pan evaporation method (ET = pan coefficient [K] * pan evaporation). Basin pan coefficients were determined for each month of each year by area weighting the pan coefficients for sugarcane, vegetables, and pasture/sod.

A pan coefficient for sugarcane of 0.8 was reported by the Agricultural Experiment Station in Belle Glade based on lysimeter studies (Mierau, 1974). Based on cultural practices in the EAA, Mierau (1974), in his analysis of the dry season irrigation demands, modified this value to 0.7. In calculating an annual water budget, CH2M-Hill (1978) used a monthly variable pan coefficient to account for crop canopy effects. They varied K from a low of 0.6 in the dry season to a peak of 0.8 in the wet season. Biswas (1988) reported ratios of evapotranspiration to pan evaporation which ranged from 0.4 to 1.4 during the growing season for various countries. He stated that this ratio is highly variable depending on climatic conditions, agricultural practice, and the variety of sugarcane grown.

In this study, K for sugarcane was calculated according to the procedure given in the Food and Agricultural Organization (FAO) Paper 24 (1977), *Crop Water Requirements*. In the FAO procedure, K is calculated as: $K = K_p K_c$. K_p is defined as a coefficient which relates the pan evaporation to the evapotranspiration from a reference crop. K_p was assumed to be 0.8. K_c is a coefficient which relates the reference crop to the actual crop in the field. Using this procedure, the monthly pan coefficient (K) for sugarcane varied from a low of 0.44 occurring shortly after planting (harvest for a ratoon crop) to a high of 0.84 during the period of peak water use.

Since there is an approximate four month sugarcane harvest season in the EAA, resulting in fields at different stages of plant growth, the monthly basin pan coefficients for sugarcane were determined by lagging the coefficients reported above. The monthly basin K for sugarcane was assumed to be the average of the lagged values.

Mierau (1974) used a pan coefficient of 0.65 for truck crops grown during the dry season. CH2M-Hill (1978) used a pan coefficient of 0.65 for vegetables for all months except June. They reported that irrigators flooded the fields during this month, accordingly, they increased K to 0.8 during June. In this study, the pan coefficients reported by CH2M-Hill (1978) were used. Although vegetables are generally not grown in South Florida during July, August, and September, K remained at 0.65 to account for evaporation from the soil surface and evapotranspiration from a rotation crop. Shih et al. (1983) used 0.65 as an average value of K for the EAA.

Mierau (1974) used an average K value of 0.58 for pasture/sod during the dry season. In this report, the pan coefficient for pasture/sod was calculated according to FAO Paper 24. Using this procedure, K varied from a low of 0.48 during January to a peak of 0.76 in July.

The monthly pan coefficients are given in Table 2. As seen in Table 2, the mean annual pan coefficients are 0.72 for sugarcane, 0.66 for vegetables, and 0.62 for pasture/sod. These values are in close agreement with the values listed by Mierau (1974).

Table 2. Pan Coefficient by Crop Type

Month	Sugarcane	Vegetables	Pasture / Sod
Jan	0.59	0.65	0.48
Feb	0.55	0.65	0.50
Mar	0.57	0.65	0.57
Apr	0.65	0.65	0.63
May	0.74	0.65	0.70
June	0.78	0.80	0.74
July	0.81	0.65	0.76
Aug	0.82	0.65	0.74
Sept	0.83	0.65	0.69
Oct	0.82	0.65	0.62
Nov	0.78	0.65	0.54
Dec	0.69	0.65	0.49
Mean	0.72	0.66	0.62

It should be noted that since the purpose of this report is to evaluate the present water use allocation criteria by comparing actual water use with the theoretical crop water requirement, the coefficients listed in Table 2 were not calibrated using existing data. Lin and Gregg (1988), using a mass balance approach, calibrated monthly pan coefficients for the pan evaporation data recorded at the Belle Glade Agricultural Experiment Station and for the pan evaporation data recorded at S-7. These coefficients were highly variable depending upon which station's data were used. Additionally, the calibrated coefficients did not resemble the coefficients which would be obtained using a theoretical crop water use methodology 3,simulation method

Evaporation from the Project canal surfaces was not considered in the current study. During an average year, this loss was calculated to be less than 0.5 percent of the total outflow for the study area.

Water Table Control

The depth to the water table is regulated by farmers. It is raised and lowered during the year to facilitate a variety of agricultural practices. The water table is lowered to provide storage for expected rainfall events, and to facilitate planting, harvest and other mechanical operations. The water table is raised to prevent fires in the muck soil during sugarcane burning, for weed and insect control, for frost protection, to slow soil subsidence, and to grow rice.

CH2M-Hill (1978) reported that the lowest water table elevations usually occurred after a period of heavy rainfall and prolonged pumping. Izuno and Alvarez (1987), in a sugarcane field study covering June 1986 to February 1987, reported that the average depth to the water table was approximately 1.8 feet below the ground surface. They also reported that the depth to the water table ranged from 3.7 feet below the ground surface to 0.14 feet above the ground surface.

Monthly average depths to the water table for a sugarcane site, a cattle ranch (pasture) site, and a vegetable farm site are given in CH2M-Hill's report (1978). Jones et al. (1984), defining the wet season as May-October and the dry season as November-April, reported that the average water table within the EAA is maintained 200 millimeters (approximately 8 inches) higher during the wet season than during the dry season. Shih et al. (1983) reported that the average depth to the water table is 60 centimeters (24 inches) during the dry season (November-April) and 45 centimeters (18 inches) during the wet season (May-October). They further reported that raising the water table from 24 inches to 18 inches below the ground surface requires 1.2 inches of water (Shih et al., 1983).

In this report, it was assumed that the basin average wet and dry season depths to the water table were primarily a function of rainfall availability. Seasonal fluctuations in the average basin water table were assumed to require no supplemental water.

The water required to facilitate various agricultural practices was accounted for in the following manner. Fluctuation of the water table for weed and insect control was assumed to require no supplemental water. This water requirement was assumed to be met from either storage in the primary canals, from excess rainfall, or from circulation within the basin (as one farmer lowers his water table another may raise his). Water required for frost protection should be needed for a few days to one week at most; this water would be returned to the Project canal system after the frost ends and these volumes should cancel in a monthly water budget. The water required as a fire control measure when burning sugarcane is not demanded simultaneously by all the sugarcane growers, but is required by various growers over the cane harvest season of mid-October through March. The water table is raised approximately one week to ten days prior to burning the cane to prevent the muck soil from burning. After burning the cane, the water table is dropped to facilitate harvest. It was assumed that the water required to raise the water table would equal the amount released to lower it. Since these volumes would occur, roughly, in a two to three week time frame, the quantities should cancel each other in a monthly water budget.

Effective Rainfall

Effective rainfall is defined as that fraction of total rainfall which can be used to meet the crop water requirement. It is less than total rainfall due to plant interception, surface evaporation, deep percolation, and surface runoff. Dastane (1974) gives a comprehensive discussion of methods for estimating effective rainfall.

In this study, two estimates of effective rainfall were used to determine upper and lower bounds for the actual rainfall that is effective. The upper bound was assumed equal to the area's total rainfall. The lower bound was assumed equal to the depth predicted by the effective rainfall formula given in the USDA Soil Conservation Service Technical Release No. 21 (TR-21).

The SCS effective rainfall formula was developed for application to the 48 contiguous states; it is a general model and is not site specific for the special conditions existing in the EAA. The EAA is an area of little relief and the occurrence of surface runoff is minimal (Jones et al., 1984); excess rainfall generally ponds on the surface and is removed by pump systems. Jones et al. (1984) reported that the EAA is an area of negligible leakage to the Floridan aquifer and that deep percolation losses should be small. Because the primary losses considered in the SCS formula are surface runoff and deep percolation, it is felt that the SCS procedure results in a conservative estimate of effective rainfall for the EAA.

The SCS effective rainfall formula has been applied by Fan (1983) and Shih et al. (1983) to South Florida conditions; however, it has not been rigorously verified using field data. Since 1985, the Regulation Department has used the SCS effective rainfall formula to determine the water use allocation for crops.

The SCS effective rainfall formula is:

$$re = (0.70917 rt^{0.82416} - 0.11556)(10^{0.02425\,u})f$$

and

$$f = 0.531747 + 0.295164\,D - 0.057697\,D^2 + 0.003804\,D^3$$

where

D = usable soil water storage

re = monthly effective rainfall in inches

rt = monthly total rainfall in inches

u = monthly consumptive use in inches

f = soil water storage factor

D was set at 3.54 inches (15 percent water storage capacityof sooil) during the dry season, corresponding to a water table depth of 24 inches (Shih et al., 1983). The Regulation Department (1985) used a value of D equal to 3.6 inches for the organic soils in the EAA.

Required Irrigation

Monthly required irrigation (supplemental water requirement) was estimated using the methodology presented by Mierau (1974). The difference between evapotranspiration and effective rainfall was termed the *required irrigation* (Mierau, 1974, labeled this quantity *ET Deficit*). Required irrigation was constrained to be greater than or equal to zero, under the assumption that rainfall in excess of the crop water requirement would be discharged as pumped runoff.

RESULTS

Applied irrigation, in inches per irrigated acre, are given in Table 3 and shown in Figure 2 for the dry seasons of 1963-1987 and the wet seasons of 1970-1987. The nomenclature used in this report denotes a given dry season by the year in which it ends; for example, the 1963 dry season is defined as November and December 1962 and January through May 1963. Applied irrigation data for the dry seasons of 1963-1970 were taken from Mierau (1974).

The mean wet season (1970-1987) applied irrigation was 2.1 inches per irrigated acre. The mean dry season applied irrigation (1971-1987) was 7.7 inches. Mierau (1974) reported that the mean applied irrigation during the 1963-1972 dry seasons was 8.4 inches. Mean applied irrigation for the combined period of the 1963-1987 dry seasons was 7.9 inches.

Dry season applied irrigation versus rainfall for the dry seasons of 1963-1987 is shown in Figure 3. Figure 4 depicts applied irrigation versus rainfall for the wet seasons of 1970-1987. As expected, the applied irrigation is inversely related to seasonal rainfall. Mean dry season rainfall during 1963-1987 was approximately 17.4 inches, close to the long term mean dry season rainfall (1930-1985) of 17.7 inches (Sculley, 1986). Mean rainfall during the wet seasons of 1970-1987 was 30.9 inches, 4.3 below the long term mean wet season rainfall (1929-1985) of 35.2 inches (Sculley, 1986).

In assuming total rainfall as effective for meeting the crop water requirement, Mierau (1974) observed that during irrigation seasons (dry seasons) with below normal rainfall, irrigation was generally applied at rates below theoretical crop

Table 3. Applied Irrigation and Rainfall

Year	Dry Season		Wet Season	
	Irrigation, Inches	Rainfall, Inches	Irrigation, Inches	Rainfall, Inches
1963	6.9 [a]	15.3 [a]		
1964	5.3 [a]	20.6 [a]		
1965	8.5 [a]	12.5 [a]		
1966	7.0 [a]	14.4 [a]		
1967	15.7 [a]	8.9 [a]		
1968	8.9 [a]	18.0 [a]		
1969	8.1 [a]	18.1 [a]		
1970	6.6 [a]	28.7 [a]	1.5	29.4
1971	11.6	8.4	0.6	36.2
1972	5.0	24.2	3.0	23.1
1973	6.3	16.1	1.2	31.4
1974	11.4	9.5	0.9	36.3
1975	14.2	12.6	0.1	39.0
1976	8.6	16.8	1.6	27.1
1977	8.6	17.1	2.3	29.5
1978	4.3	23.2	0.5	37.0
1979	7.0	20.2	5.3	30.4
1980	3.4	24.2	4.7	23.5
1981	8.4	11.4	3.6	29.2
1982	5.8	24.1	0.6	37.4
1983	5.9	21.1	1.0	31.6
1984	8.4	21.4	3.8	21.2
1985	10.5	14.1	2.4	34.8
1986	5.3	16.2	0.8	34.0
1987	5.5	16.8	4.4	24.6
Mean (63-87)	7.9	17.4		
Mean (71-87)	7.7	17.5		
Mean (70-87)			2.1	30.9

[a] Source: Mierau, 1974.

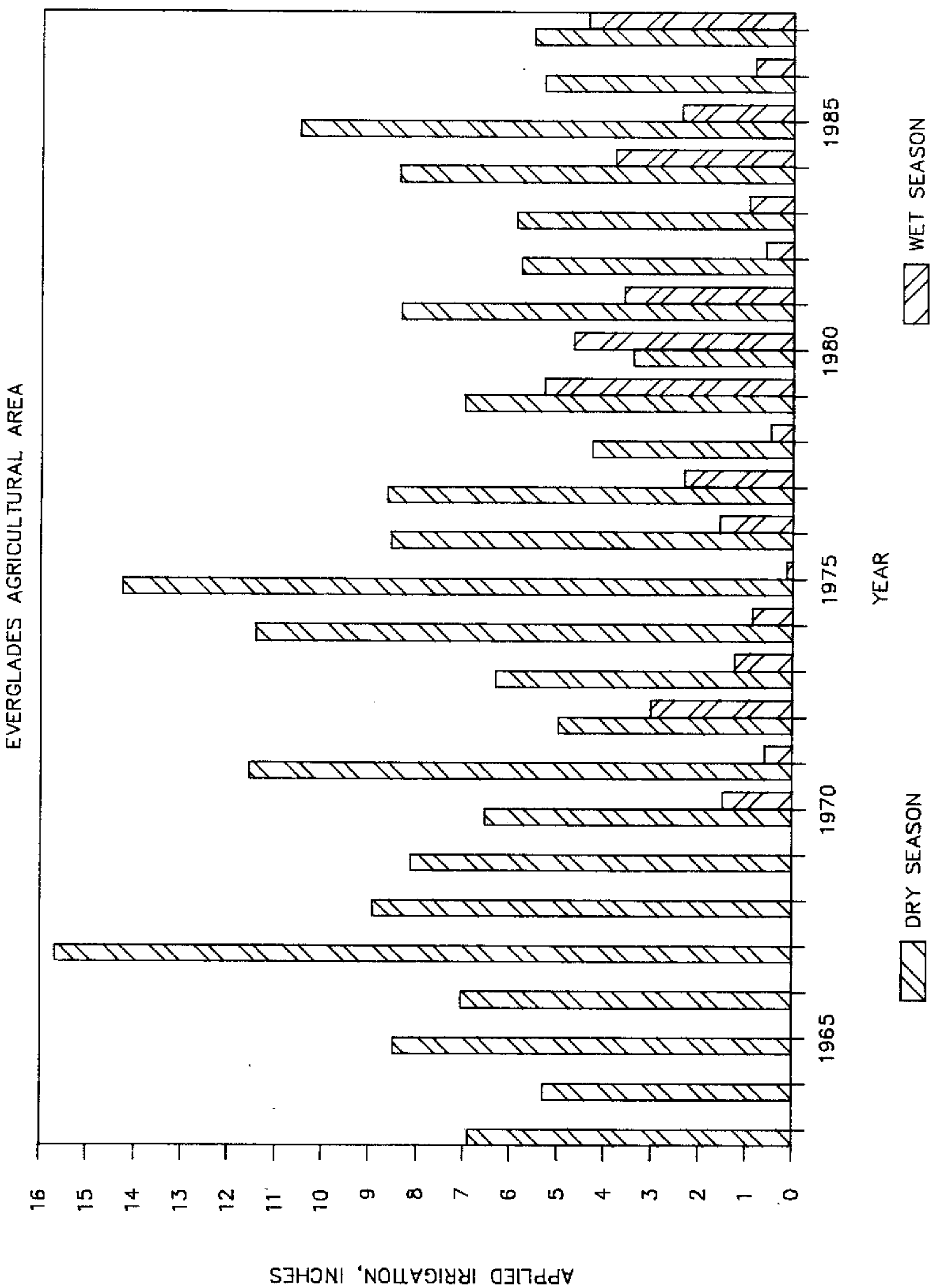

FIGURE 2. APPLIED IRRIGATION

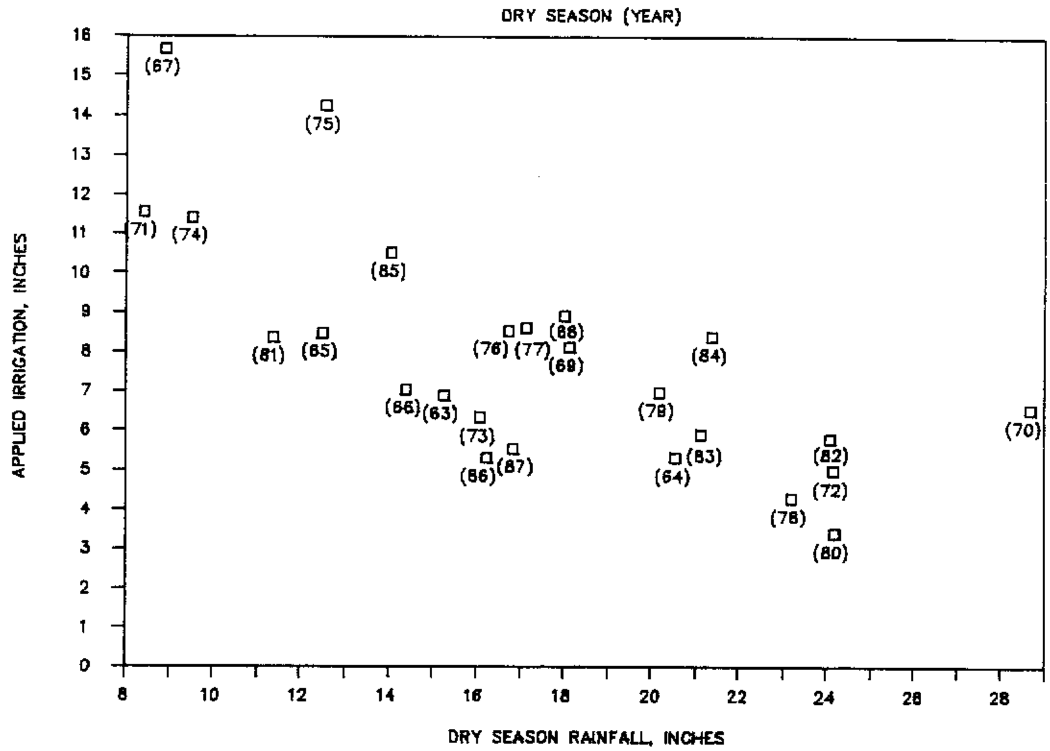

FIGURE 3. RAINFALL VERSUS APPLIED IRRIGATION

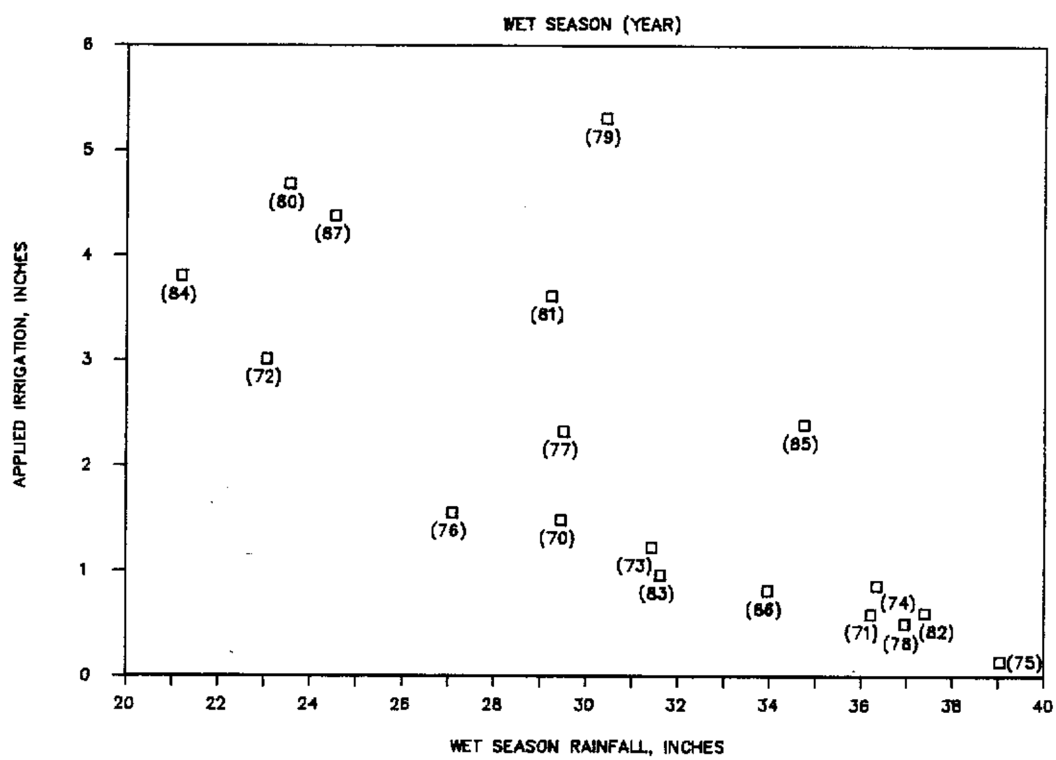

FIGURE 4. RAINFALL VERSUS APPLIED IRRIGATION

water requirement. During dry seasons with above normal rainfall, however, Mireau reported that there was a tendency to apply irrigation at rates greater than the theoretical crop water requirement. Figure 5 displays both the difference between actual and mean dry season rainfall, and the difference between applied and required irrigation, using the SCS effective rainfall formula. Figure 6 displays both the difference between actual and mean dry season rainfall and the difference between applied and required irrigation, assuming all rainfall is effective. Mierau's data for the dry seasons of 1963-1970 are included in Figure 6.

In general, for the period 1971-1987 irrigation was applied at rates less than the theoretical crop water requirement during dry seasons with below normal rainfall. This observation, in agreement with Mierau (1974), is true for effective rainfall as predicted by the SCS effective rainfall formula in (9 of 10) dry seasons with below normal rainfall, and by the effective rainfall assumption in (6 of 10) dry seasons with below normal rainfall.

During dry seasons (1971-1987) with above normal rainfall (assuming all rainfall is effective) irrigation was applied at rates greater than that the theoretical requirement in six of seven dry seasons (Figure 6). Irrigation was applied at rates less than the theoretical requirement during all dry seasons with above normal rainfall (Figure 5) using the effective rainfall formula as predicted by the SCS equation.

During the 1971-1987 dry seasons, the SCS effective rainfall formula resulted in required irrigation depths, which were greater than the applied irrigation depths in 16 of 17 dry seasons (Figure 5). The applied irrigation exceeded required irrigation in only the 1975 dry season, a dry season with below normal rainfall.

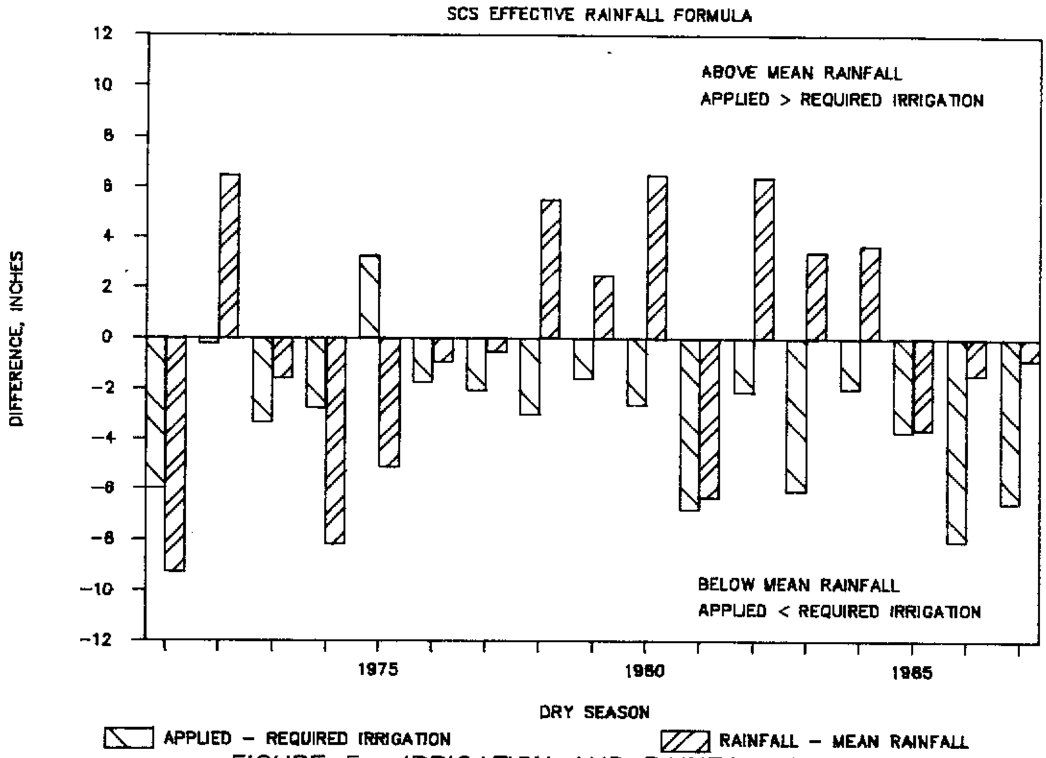

FIGURE 5. IRRIGATION AND RAINFALL DIFFERENCES

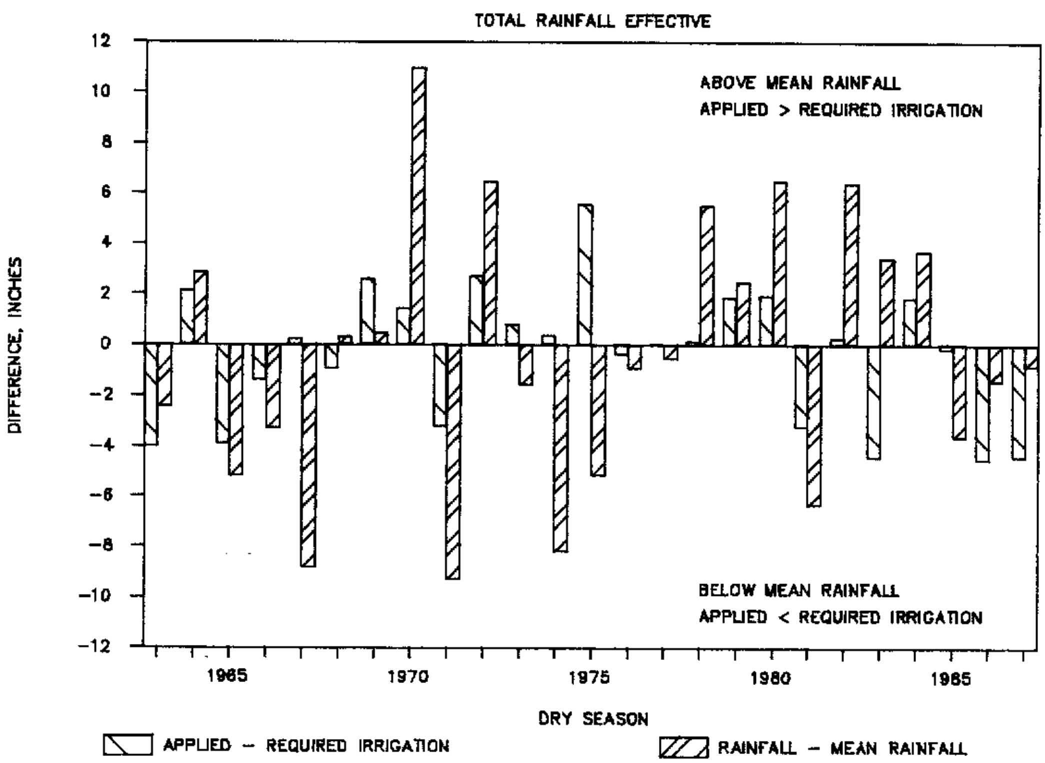

FIGURE 6. IRRIGATION AND RAINFALL DIFFERENCES

Monthly estimates of required and applied irrigation for the 1971-1987 dry seasons are shown in Figures 7-23. These figures depict the required irrigation depths predicted by both the SCS effective rainfall formula and total rainfall effective assumption. The area between the two curves is shaded to indicate the range within which the applied irrigation should lie. Table 4 summarizes the information and the appendix contains a listing of the monthly values.

The mean dry season required irrigation, using the SCS rainfall effective formula, was approximately 10.9 inches. Mean dry season (1971-1987) applied irrigation was 7.7 inches; the difference between mean applied and mean required irrigation was -3.2 inches.

The mean dry season required irrigation was approximately 8.0 inches, assuming all rainfall is effective. Mean dry season (1971-1987) applied irrigation was 7.7 inches; the difference between mean applied and mean required irrigation was -0.3 inches. Including Mierau's (1974) estimates of required and applied irrigation for the 1963-1970 dry seasons, the mean required irrigation was 8.3 inches, mean dry season applied irrigation was 7.9 inches, and the difference was -0.4 inches.

Monthly mean, maximum, and minimum values of applied and required irrigation are shown in Figures 24 and 25. April was found to have the highest mean applied irrigation, with May having the second highest. May typically marks the end of the dry season and the beginning of the wet season.

Mass curves of flow entering and leaving the study area during 1970-1987 are shown in Figure 26. Inflow to the EAA as applied irrigation generally enters from

Table 4. Dry Season Irrigation in Inches

Dry Season	Applied	Required SCS Effective Rainfall	Required Total Effective Rainfall
1963	6.9 [a]		10.9 [a]
1964	5.3 [a]		3.2 [a]
1965	8.5 [a]		12.4 [a]
1966	7.0 [a]		8.5 [a]
1967	15.7 [a]		15.4 [a]
1968	8.9 [a]		9.9 [a]
1969	8.1 [a]		5.5 [a]
1970	6.6 [a]		5.1 [a]
1971	11.6	17.6	14.8
1972	5.0	5.2	2.3
1973	6.3	9.7	5.5
1974	11.4	14.2	11.1
1975	14.2	11.0	8.7
1976	8.6	10.3	9.0
1977	8.6	10.7	8.6
1978	4.3	7.3	4.2
1979	7.0	8.6	5.1
1980	3.4	6.1	1.5
1981	8.4	15.2	11.6
1982	5.8	7.9	5.5
1983	5.9	12.0	10.3
1984	8.4	10.4	6.5
1985	10.5	14.2	10.7
1986	5.3	13.4	9.8
1987	5.5	12.1	10.0
Mean (63-87)	7.9		8.2
Mean (71-87)	7.7	10.9	8.0

[a]Mierau, 1974.

Lake Okeechobee, but can also come from the WCAs if conditions permit. Total outflow from the EAA was divided between water discharged to Lake Okeechobee and water discharged to the WCAs.

During 1970-1987, the cumulative volume of water discharged from the EAA to Lake Okeechobee and the WCAs was greater than the cumulative applied irrigation. This is evidenced in Figure 26 by the divergence of the mass lines of total outflow and inflow (applied irrigation). A similar trend was evident during the period 1962-1971 in a graph contained in Mierau's 1974 report. Therefore, by using the cumulative flow data, the volume of annual pumped drainage water relative to the EAA's annual rainfall (basin yield) was estimated. The basin yield estimates do not represent natural (pristine) rainfall/runoff relationships of the basin, rather, they represent the volume of water which farmers feel they must remove to sustain their level of productivity. It is the volume of water which the farmers perceive to be surplus.

Cumulative flow out of the EAA for the 18-year period was approximately 18,650,000 acre-feet (Figure 26). Cumulative applied irrigation (water entering the EAA) for the same period was approximately 6,356,000 acre-feet. The net surplus water for the EAA was equal to the difference of 12,294,000 acre-feet for 18 years, or approximately 683,000 acre-feet per year. By using the mean irrigated acreage of 423,000 acres, the surplus water per irrigated acre was approximately 19.4 inches per year. Mean annual rainfall for the EAA, based on 59 years of record (1929-87), was 52.8 inches; therefore, basin yield is approximately 37 percent of the long term mean annual rainfall. Mean annual rainfall during the study period (1970-1987) was 49.2 inches. Using this estimate of mean annual rainfall results in a basin yield of approximately 39 percent.

CH2M-Hill (1978), based on three intensive study sites, reported that annual pumpage from a sugarcane field was approximately 24 inches per irrigated acre, from a cattle ranch was approximately 13 inches, and from a vegetable farm was approximately 32 inches. If seepage at the vegetable farm was subtracted, the annual pumpage was approximately 18 inches. They further reported that the ratios of pumped water to rainfall were 0.58 (58 percent) for the sugarcane farm, 0.35 (35 percent) for the cattle ranch, and 0.74 (74 percent), or 0.41 (41 percent) subtracting seepage, at the vegetable farm site.

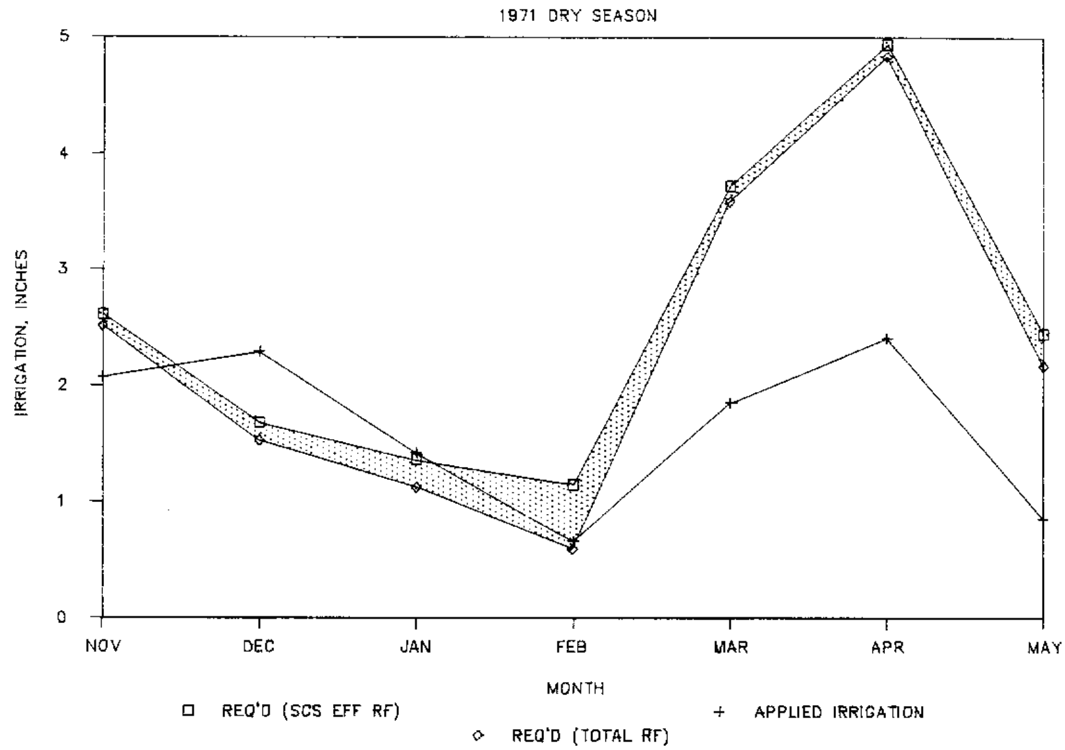

FIGURE 7. APPLIED AND REQUIRED IRRIGATION

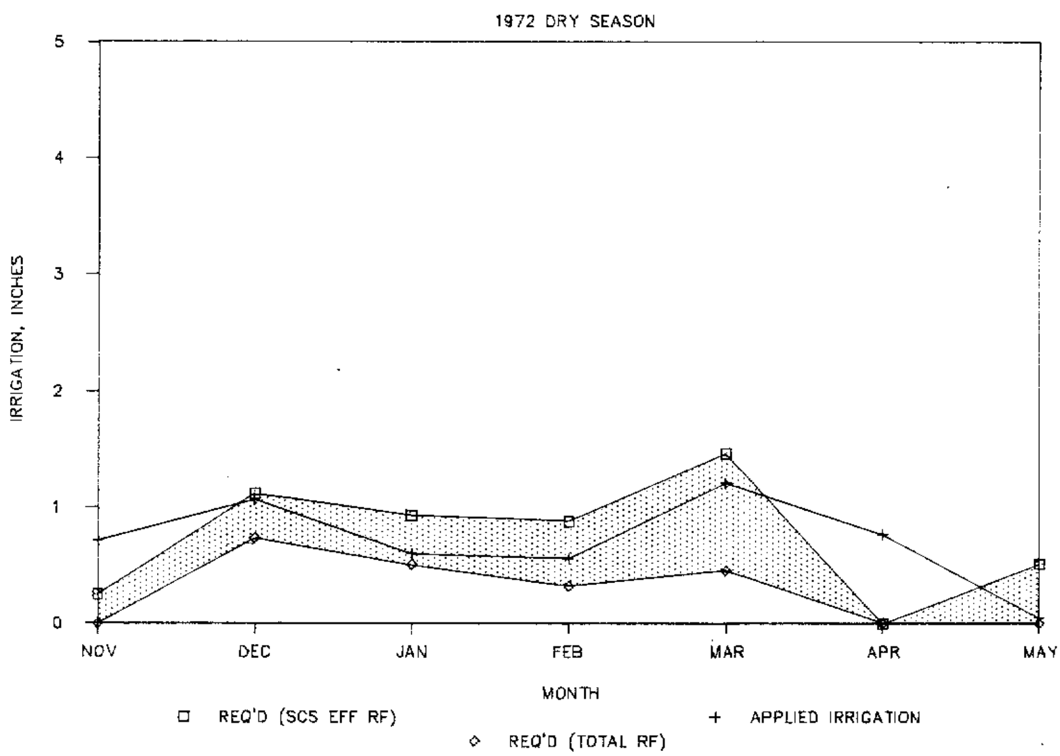

FIGURE 8. APPLIED AND REQUIRED IRRIGATION

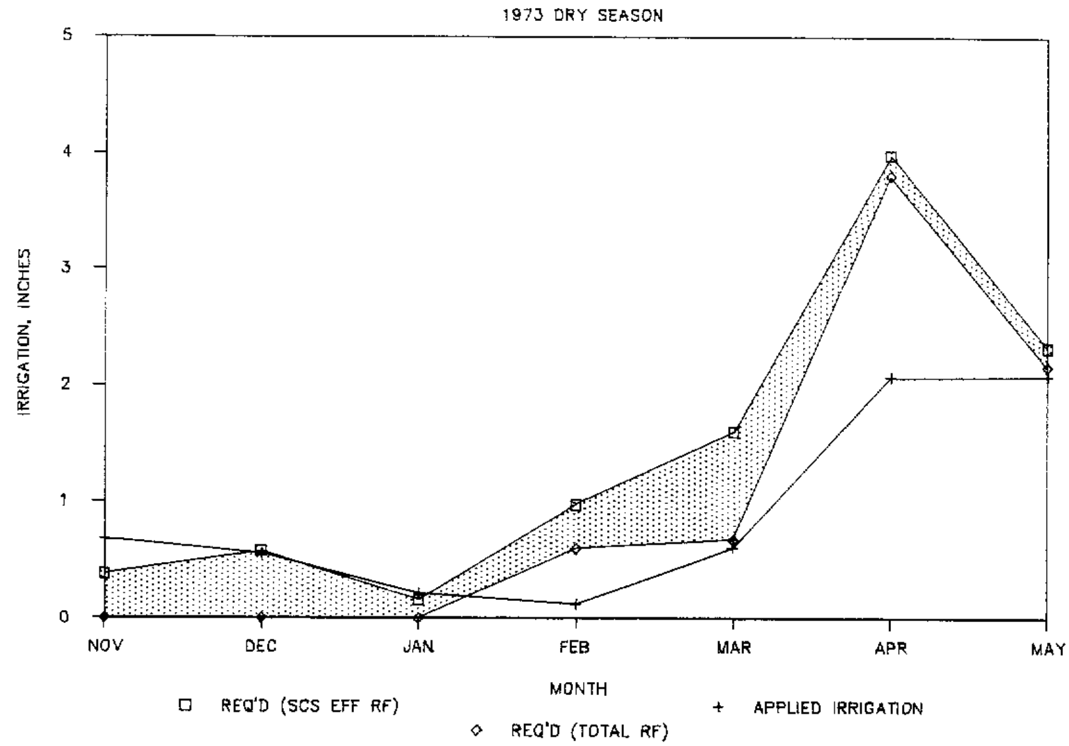

FIGURE 9. APPLIED AND REQUIRED IRRIGATION

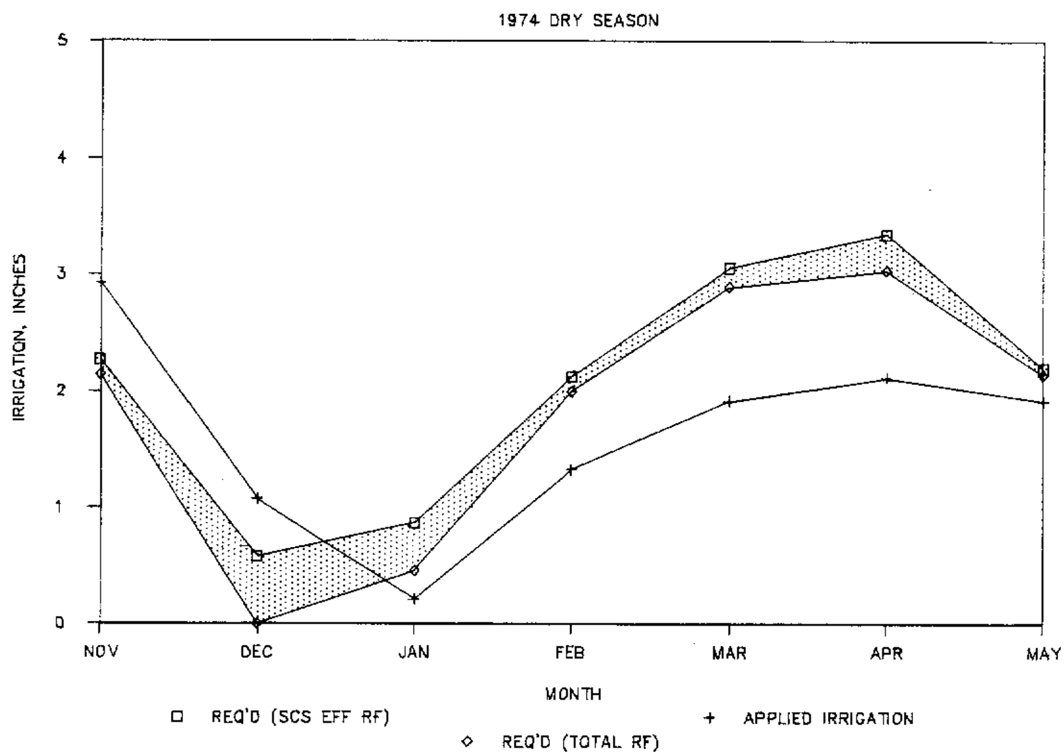

FIGURE 10. APPLIED AND REQUIRED IRRIGATION

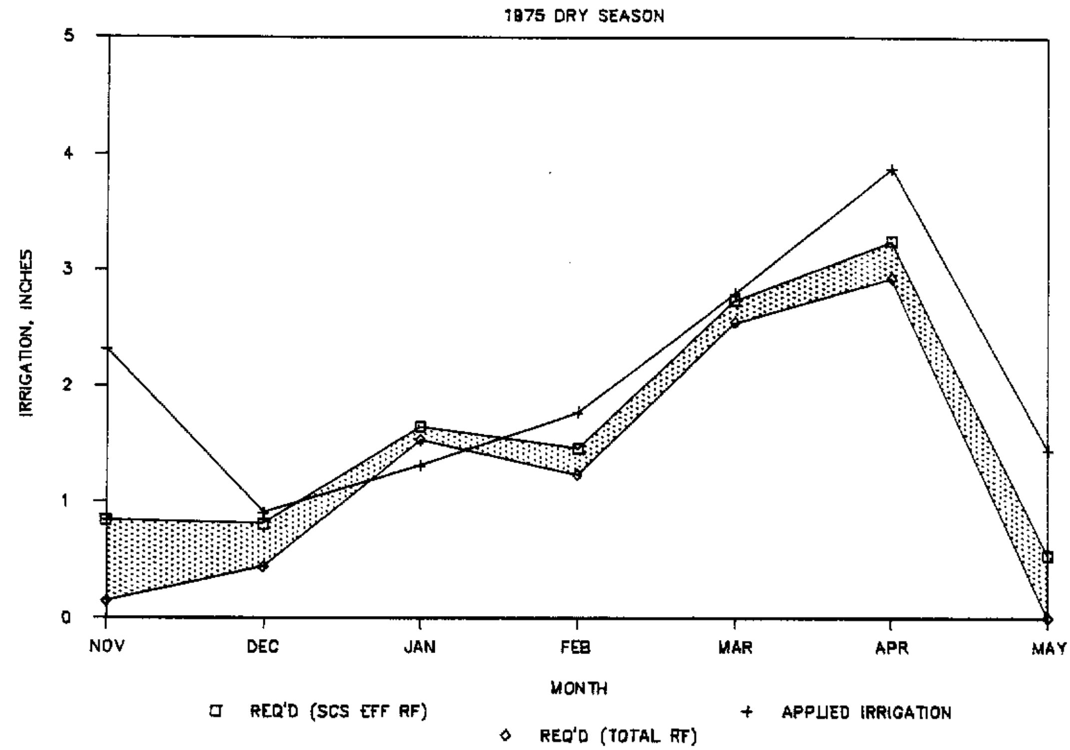

FIGURE 11. APPLIED AND REQUIRED IRRIGATION

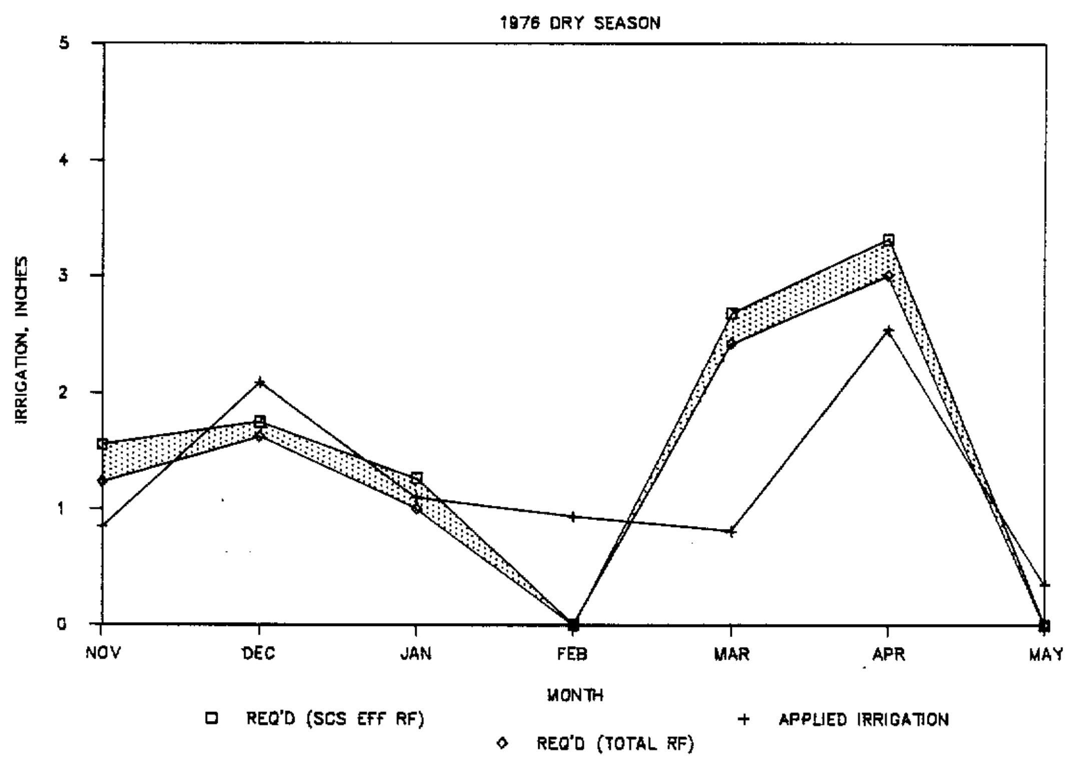

FIGURE 12. APPLIED AND REQUIRED IRRIGATION

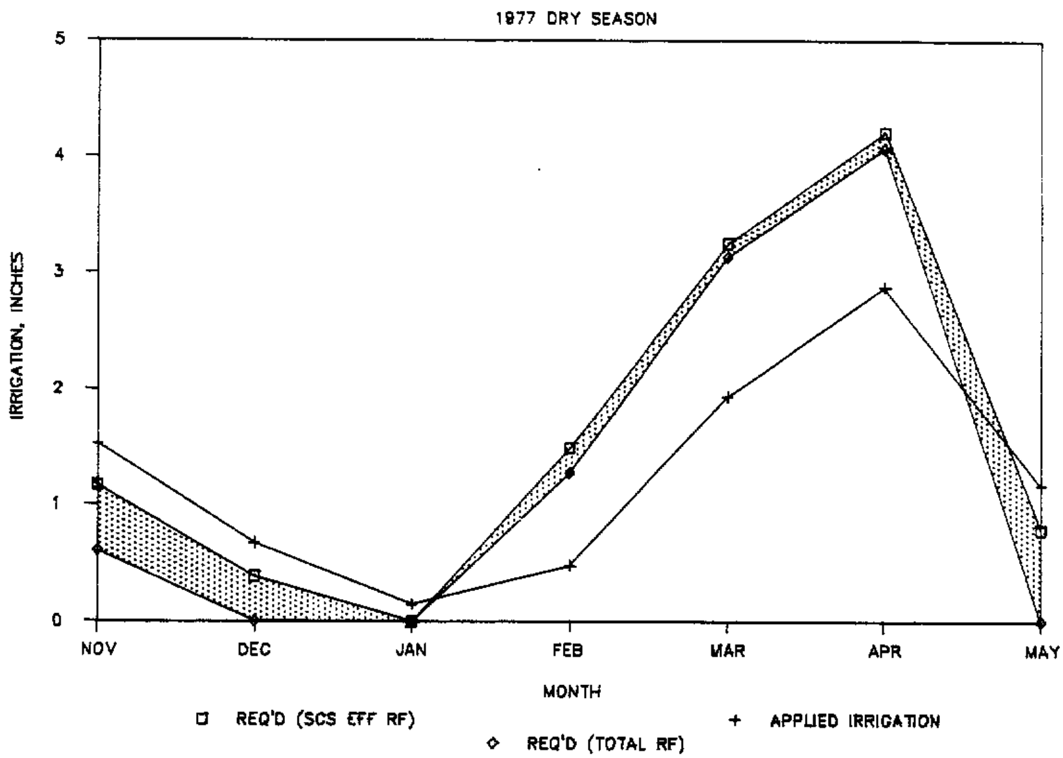

FIGURE 13. APPLIED AND REQUIRED IRRIGATION

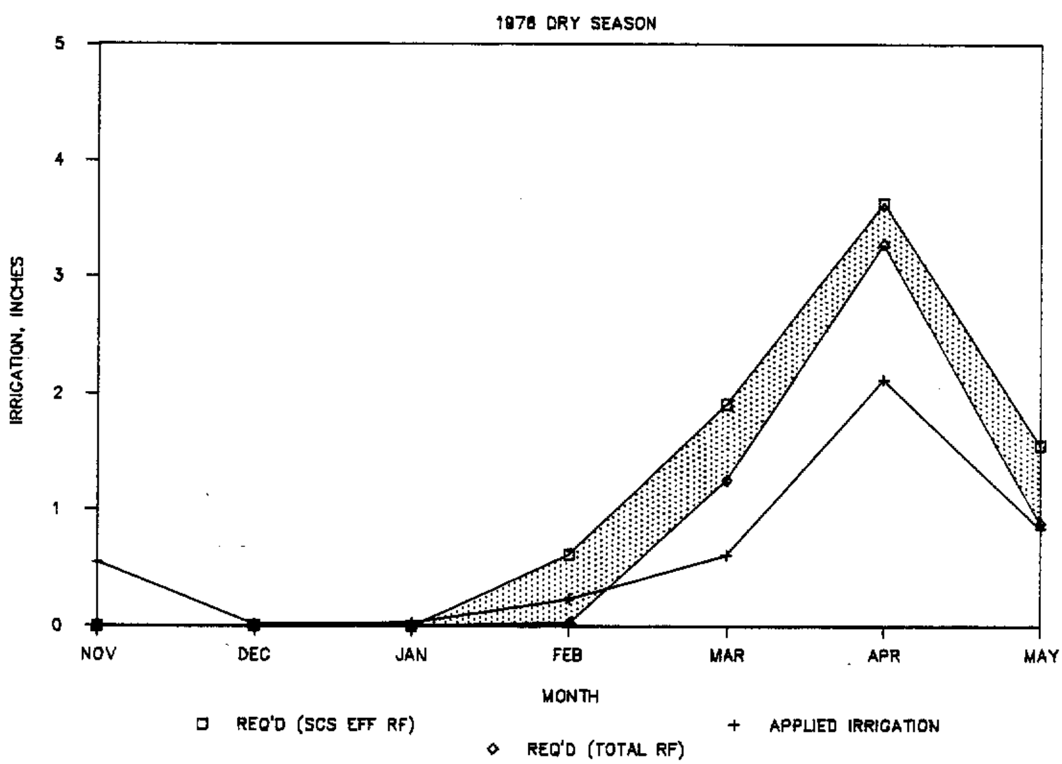

FIGURE 14. APPLIED AND REQUIRED IRRIGATION

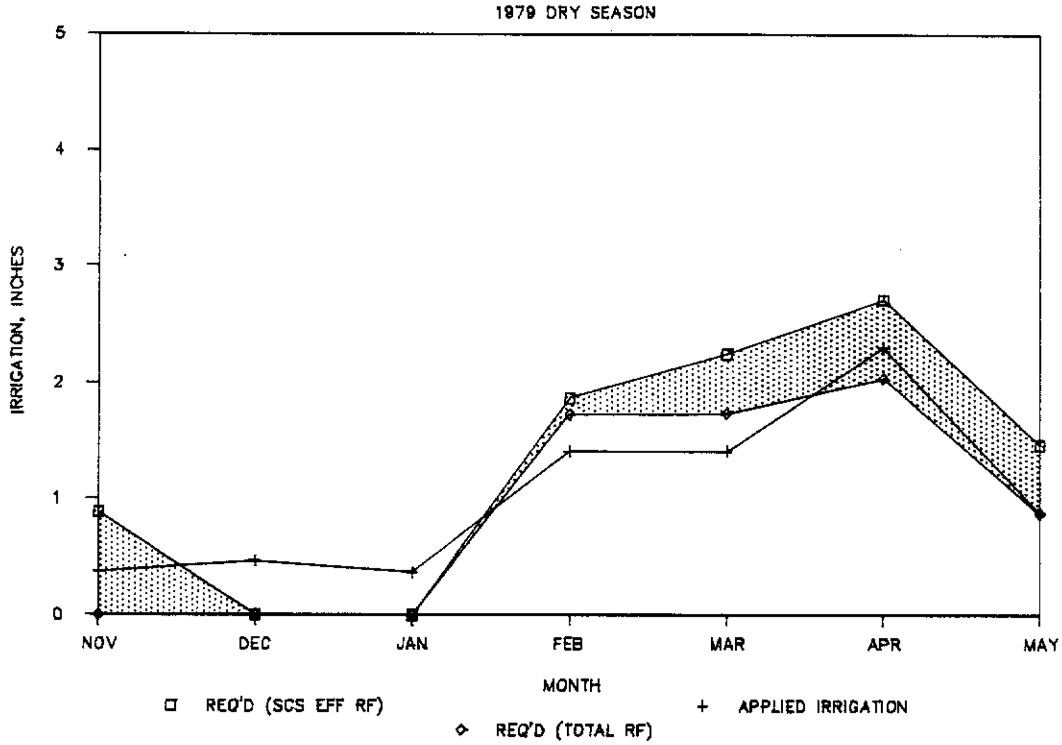

FIGURE 15. APPLIED AND REQUIRED IRRIGATION

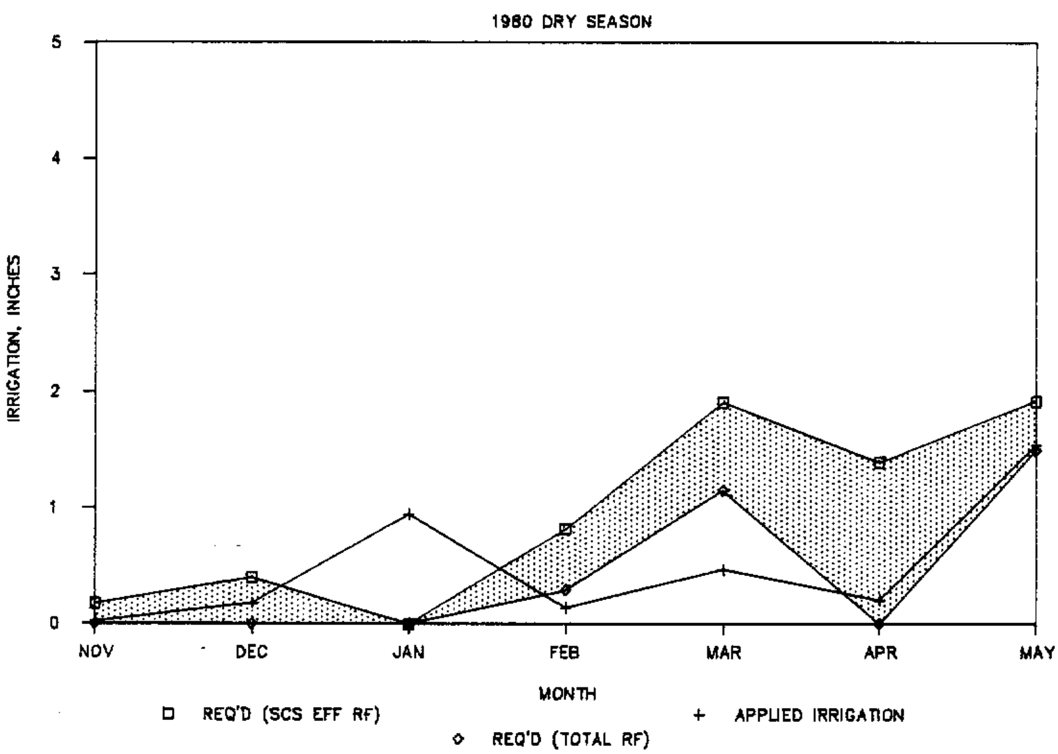

FIGURE 16. APPLIED AND REQUIRED IRRIGATION

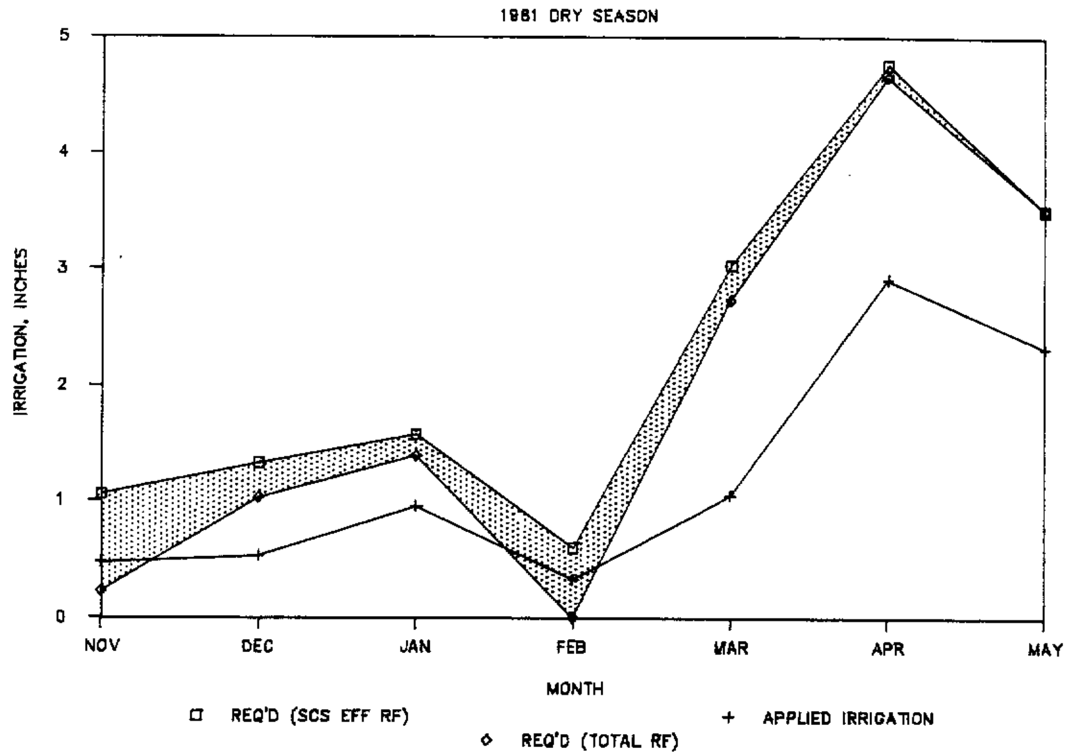

FIGURE 17. APPLIED AND REQUIRED IRRIGATION

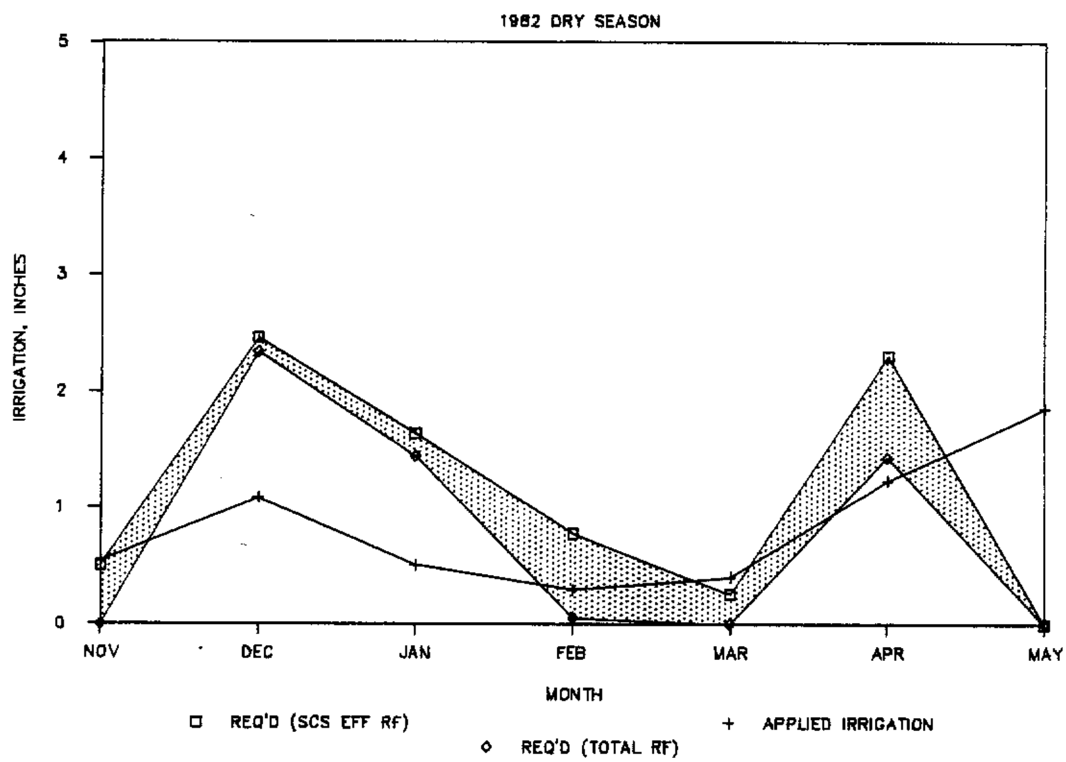

FIGURE 18. APPLIED AND REQUIRED IRRIGATION

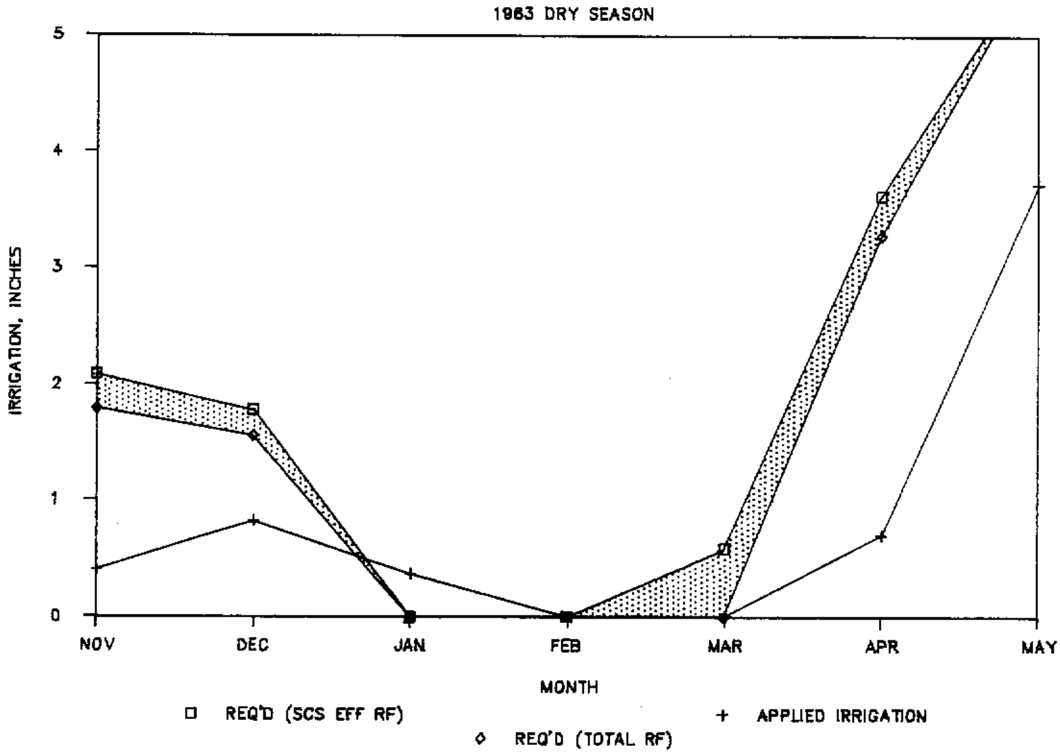

FIGURE 19. APPLIED AND REQUIRED IRRIGATION

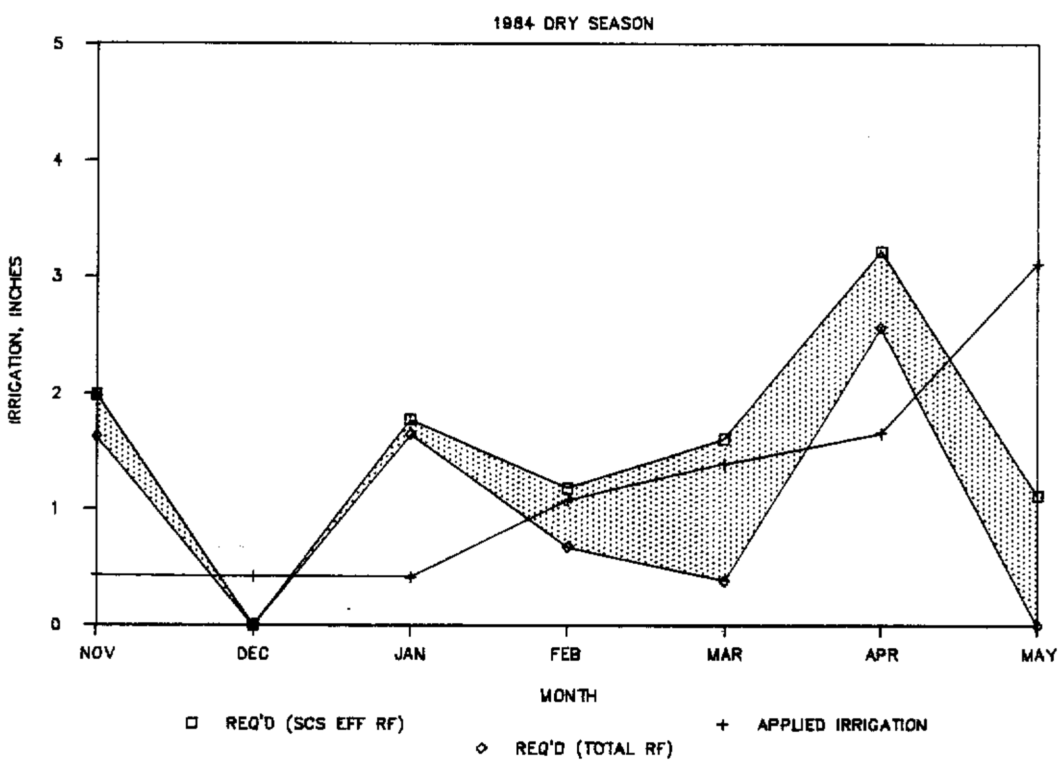

FIGURE 20. APPLIED AND REQUIRED IRRIGATION

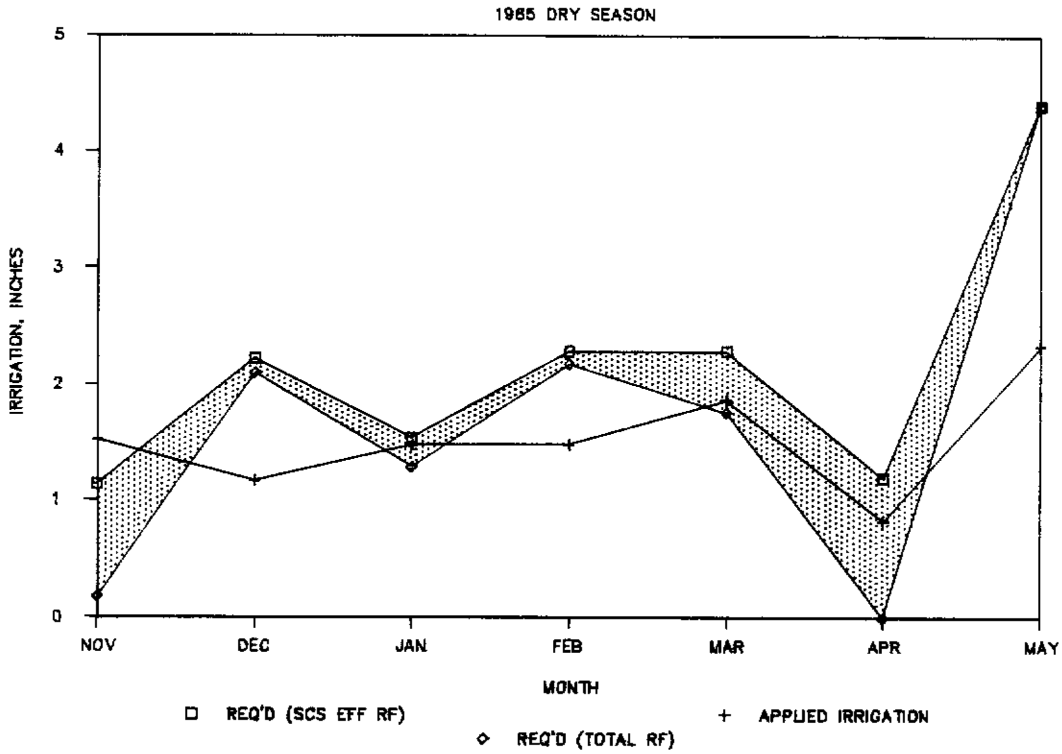

FIGURE 21. APPLIED AND REQUIRED IRRIGATION

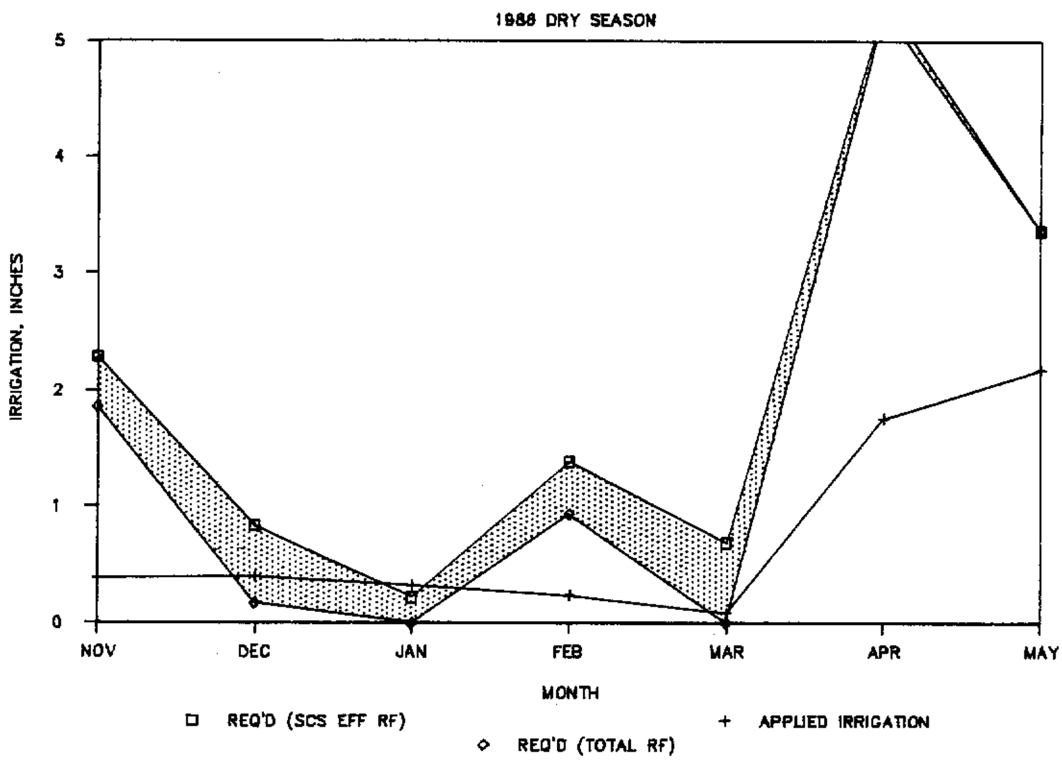

FIGURE 22. APPLIED AND REQUIRED IRRIGATION

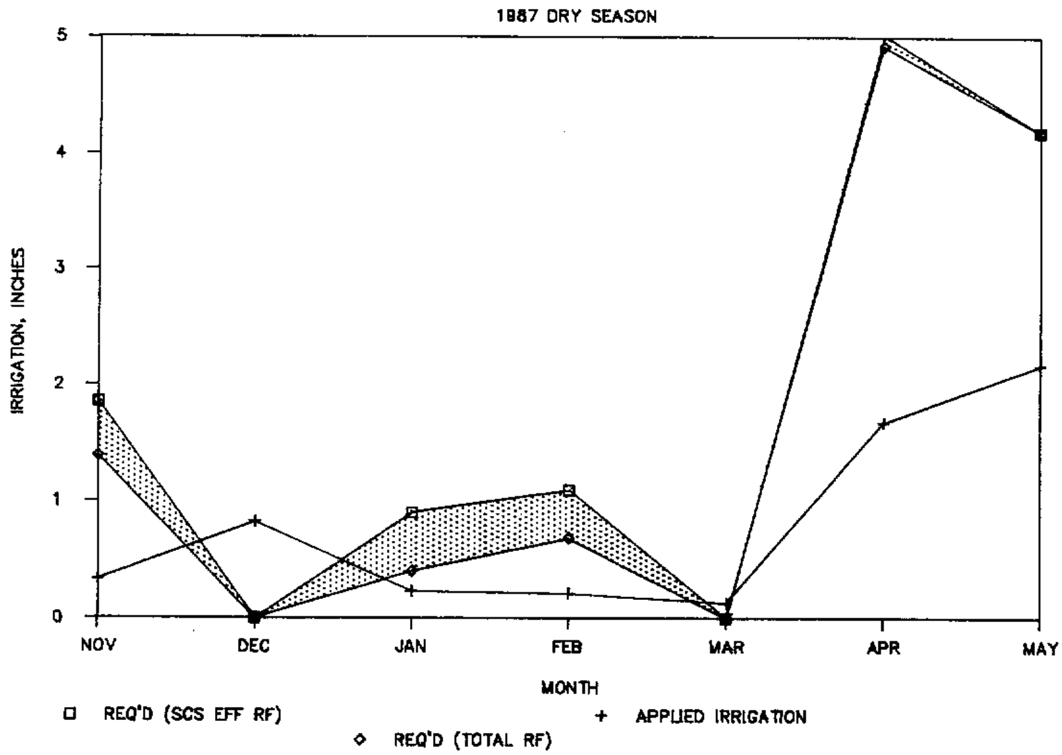

FIGURE 23. APPLIED AND REQUIRED IRRIGATION

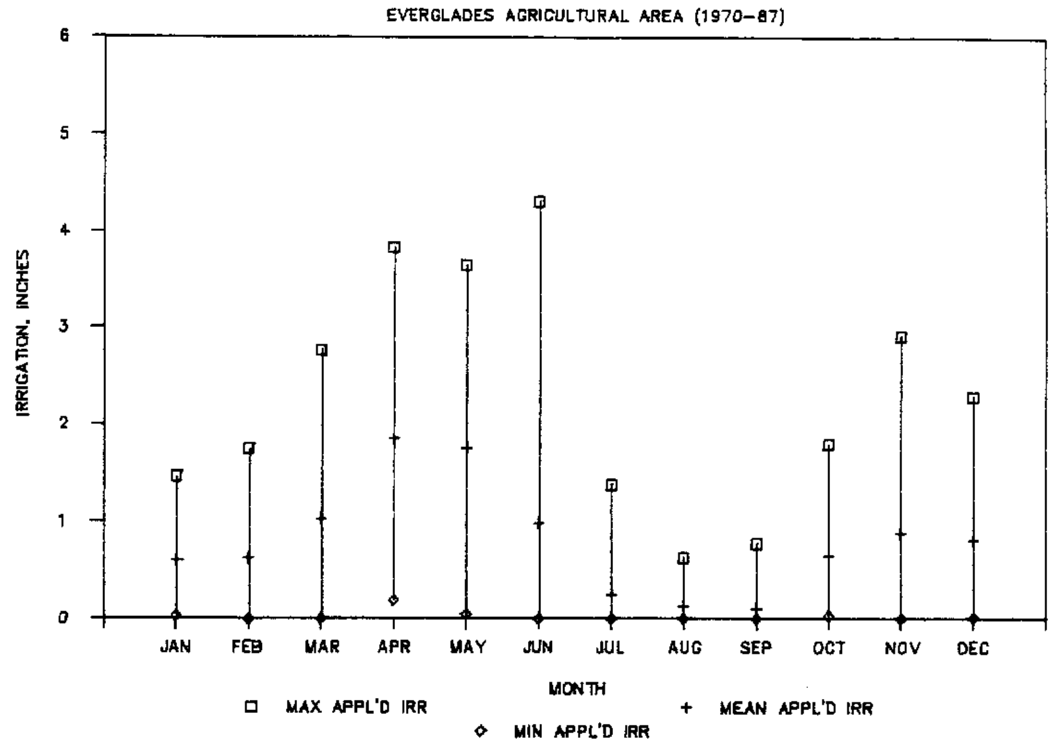

FIGURE 24. MONTHLY MEAN APPLIED IRRIGATION

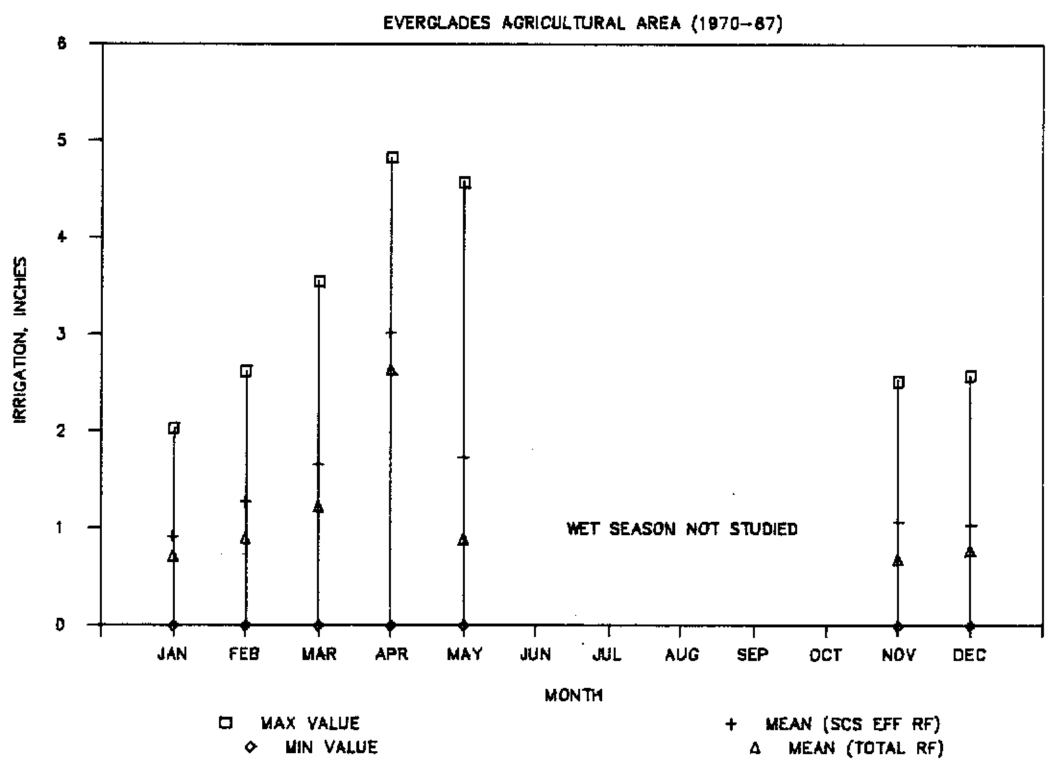

FIGURE 25. MONTHLY MEAN REQUIRED IRRIGATION

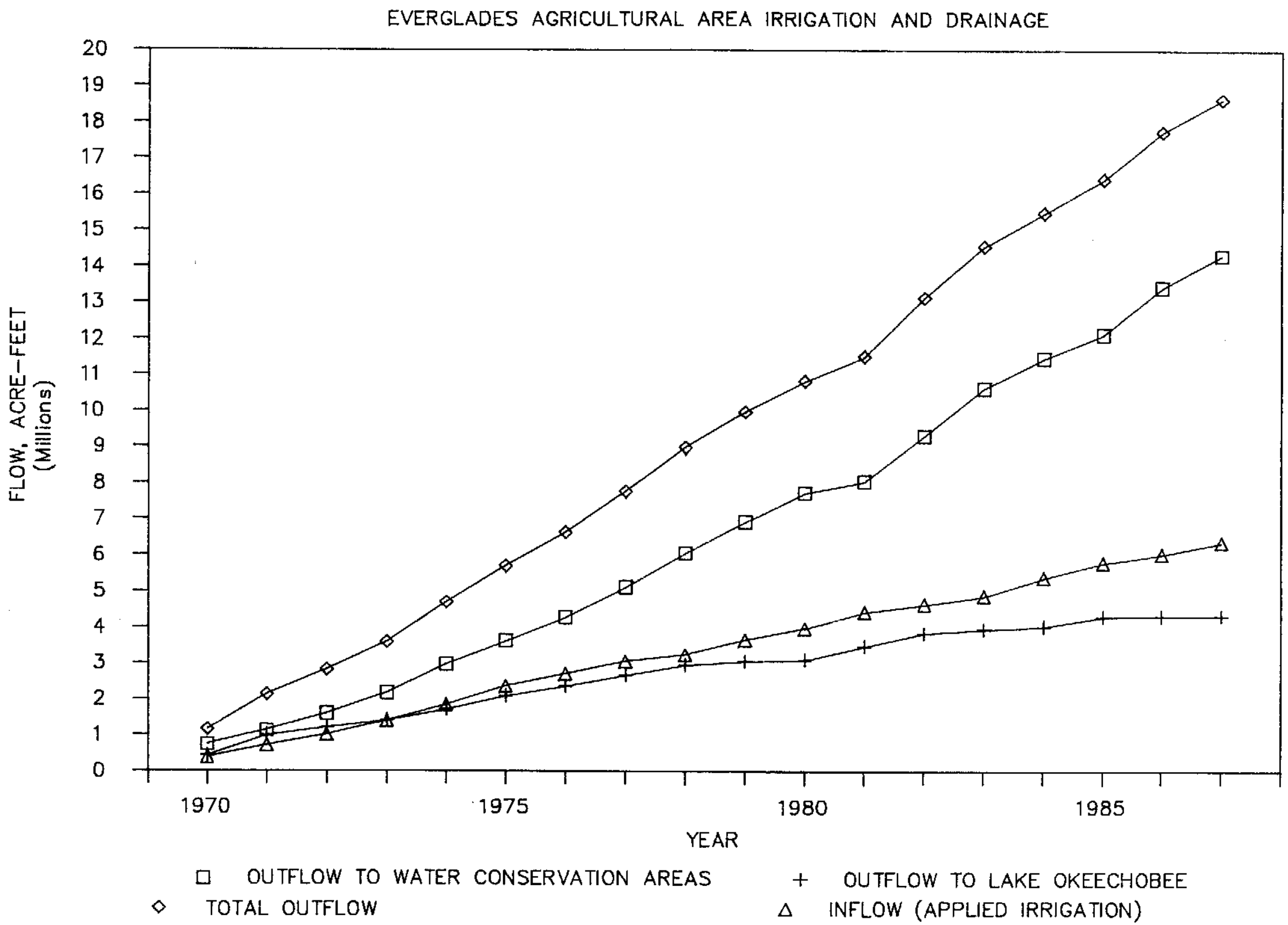

FIGURE 26. ANNUAL FLOW VOLUME MASS CURVES

DISCUSSION

Irrigation was applied in the study area during both the wet and dry seasons, with most of it being applied during the dry seasons. Mean dry season applied irrigation was approximately 8 inches; mean wet season applied irrigation was approximately 2 inches. As seen in Figures 3 and 4, applied irrigation increased with a decrease in rainfall.

In general, during the 1971-1987 dry seasons with below normal rainfall, irrigation was applied at rates less than the theoretical crop water requirement. This observation, in agreement with Mierau (1974), is true for effective rainfall as predicted by either the SCS effective rainfall formula in 9 of 10 dry seasons with below normal rainfall, or total rainfall effective assumption in 6 of 10. Possible reasons for the applied irrigation being less than the theoretical water requirement include: voluntary water use restrictions by the irrigator, District imposed water use restrictions, or individual system withdrawal deficiencies which automatically limit withdrawals during periods of low Project canal stages.

During dry seasons (1971-1987) with above normal rainfall, irrigation was applied at rates greater than that theoretically required, assuming all rainfall is effective in 6 of 7 dry seasons. Mierau (1974) reported a similar trend for the 1963-1972 dry seasons. Mireau also stated that the overapplication may be more apparent than real, due to the method of calculating irrigation requirements on a monthly basis. During a dry season with above normal rainfall, the majority of the rainfall may have occurred during one or two intense storms in which much of the rainfall would have been discharged from the study area. By using monthly statistics, however, the rainfall is assumed to be uniformly distributed throughout the month. Irrigation was applied at rates less than those predicted by the SCS effective rainfall formula during all of the 1971-1987 dry seasons with above normal rainfall.

Using the SCS effective rainfall formula, the theoretical required irrigation was greater than that applied in 16 of 17 dry seasons (Figure 5). Applied irrigation exceeded required irrigation in only the 1975 dry season, a dry season with below normal rainfall.

During the 1975 dry season, between 3.2 (SCS effective rainfall formula) and 5.6 (total rainfall effective) inches of irrigation were applied in excess of the estimated crop water requirement. Dry season rainfall for the EAA was approximately 12.6 inches, 5.1 inches below the mean dry season rainfall of 17.7 inches.

Mierau (1974) reported that irrigation may be applied in excess of that required during periods of an ample water supply. He stated that a high stage in Lake Okeechobee, and the corresponding Project canal stages maintained by the irrigation release practice of the District, would indicate an ample water supply. He observed that a high Lake Okeechobee stage was present during the 1967 dry season, a dry season with below normal rainfall in which irrigation was applied at rates greater than those theoretically required.

During the 1975 dry season, the stages existing in Lake Okeechobee indicated an ample water supply. On November 1, 1974, the stage in Lake Okeechobee was 15.23 feet NGVD, within a few tenths of the regulation schedule of 14.0-15.5 feet NGVD. At the end of the 1975 dry season (May 31), the Lake Okeecchobee stage was approximately 12.1 feet NGVD. The ample storage existing in Lake Okeechobee during the 1975 dry season is discussed in detail in Summary of the Condition of South Florida Water Storage Areas in the 1974-75 Dry Season (Central & Southern Florida Flood Control District, 1975).

During the study period of 1970-1987, the 1981 dry season is considered to be severe. The volumes of required and applied irrigation were examined for the 1981 dry season to determine its effects. Lin et al. (1984) reported that the drought of 1980-1982 had, for some basins within the boundaries of the District, a return period less than 1 in 100 years. In the current study, the 1981 dry season rainfall for the EAA was estimated to be 11.4 inches, 6.3 inches below the mean dry season rainfall. The 1981 wet season rainfall was estimated to be 29.2 inches, 6.0 inches below the mean wet season rainfall. Applied irrigation during the 1981 dry season was 3.2 to 6.8 inches less than that theoretically required. In May 1981, the District imposed mandatory water use restrictions in the EAA, achieved by supply side management. These water use restrictions continued through June and into July (South Florida Water Management District, 1981).

To gauge the effects of the drought, sugarcane yield records were studied. According to the Florida Sugar Cane League statistics, the 1981-82 net yield for sugarcane was 28.9 tons per acre, the lowest net yield recorded for the harvests of 1967-68 through 1987-88. The mean yield for this period of record was 32.4 tons per acre, with a standard deviation of 2.3 tons per acre. The 1981-82 sugarcane yield was approximately 1.5 standard deviations below the mean. According to the Florida Agricultural Statistics Bulletins for Field Crops (1981), the low sugarcane yield was primarily due to subfreezing temperatures which occurred in December 1981 and January 1982. Shih (1984) reported that during the 1981-1982 harvest season, unusually warm weather followed these freezes and that this condition accelerated the deterioration of the sugarcane. Doty (1964) found that the freezing resistance of sugarcane is highly variable depending on the variety of sugarcane grown. Shih (1984) studied the effects of a 40 percent irrigation cutback during the month of May and reported that there was not a severe impact in yield for the variety of sugarcane he tested. In conclusion, the 1981-82 yield reduction associated with the underapplication of irrigation during the dry season, combined with below normal rainfall occurring in both the dry and wet seasons. could not be readily differentiated from the yield reduction due to the freezing temperatures.

Mierau (1974), based on the findings of his analysis, reported that there was no abuse of the District's permitting criteria for water use during 1962-1972. He stated that the maximum application withdrawal rate was substantially below that allowed. The water use permitting criteria, in effect at that time, allowed for a maximum daily withdrawal rate of 0.25 inches per acre with a maximum monthly withdrawal rate of 7.5 inches per acre.

Currently, the District's Regulation Department issues agricultural irrigation water use permits based on effective rainfall and crop evapotranspiration. The Regulation Department estimates the effective rainfall by the SCS effective rainfall formula. The predicted effective rainfall depth is then standardized to the 2- in 10-year drought through the use of a coefficient. The crop evapotranspiration is estimated by the SCS TR-21 method (modified Blaney Criddle) when measured crop water requirements are not available (RCD, 1985). Jones et al. (1984) reported that for the EAA, a modification of the Blaney Criddle method (by substituting the percent of solar radiation in place of the percent of daylight hours) gives evapotranspiration estimates closer to those observed in the field. They also reported that this method results in estimates comparable to those obtained from the pan evaporation method.

In determining the water use allocation, allowances are made for losses due to the irrigation delivery system. System efficiencies range from 50 percent for surface-gravity irrigation systems to 75 percent for sprinkler irrigation systems. The water use allocation is determined by dividing the supplemental crop water requirement, defined as the difference between crop evapotranspiration and effective rainfall, by the irrigation efficiency.

Since the present water use permitting criteria is based on crop evapotranspiration and effective rainfall, estimated by the SCS effective rainfall formula, comparisons can be made to the findings of the present study. Conclusions drawn from the present study will be conservative, as compared to the Regulation Department's criteria, since efficiency losses were not included in the calculation of the supplemental crop water requirement. However, the irrigation efficiencies listed are for individual operators and may not represent the overall basin efficiency. The water loss from one operator may be a gain for an adjacent operator, in effect, much of the efficiency losses are probably redistributed within the basin.

In this study, it was found that irrigators in the EAA study area applied less irrigation than the crop water requirement predicted by the SCS effective rainfall formula, during 16 of 17 dry seasons (Figure 5). Since the water use allocation allows for efficiency losses, this finding indicates that irrigators in the EAA study area have generally not applied irrigation in excess of the allocated quantity. This finding applies to the EAA study area as a whole and is not meant to be representative of an individual operator.

Mierau (1974) reported that during 1962-1971, the EAA functioned essentially as a "closed system". He observed that the cumulative annual volume of water pumped to Lake Okeechobee from the EAA was approximately equal to that entering the EAA from Lake Okeechobee for irrigation. Mass curves of flow entering and leaving the study area (Figure 26) show that prior to 1979 this trend continued. During 1979, the SFWMD drafted a plan, known as the Interim Action Plan (IAP), to reduce nutrient loadings to Lake Okeechobee by reducing the frequency of pumping drainage water from the EAA to Lake Okeechobee. Since 1979, due to this plan, the mass flow (applied irrigation)from the EAA to Lake Okeechobee has been less than the mass flow from Lake Okeechobee to the EAA.

Total outflow from the study area increased during 1970-1987. (As seen in Figure 26, the slope of the total outflow line increases.) This is partially due to changes in land use within the basin (increased land under agricultural production) and to modifications made to the primary canal system. Two additional culverts, G-88 and G-136, constructed by the District during the mid-1970s to early 1980, along with the L-1E canal, constructed in the early to mid-1980s, can divert additional flow from Hendry County to the Miami Canal. Because the objective of this study was to examine the current water use allocation criteria (supplemental water use), the additional outflows from the basin were not analyzed.

CONCLUSIONS

The applied irrigation and theoretical crop water requirement for the EAA study area (Figure 1) were examined. Observations were noted for the period 1970-1987 and comparisons were made to the findings in Mierau's technical publication Supplemental Water Use in the Everglades Agricultural Area (1974). The conclusions were drawn by considering the EAA study area as a basin and are not meant to represent individual operations.

1. During the 1971-1987 dry seasons with below normal rainfall, irrigation was generally applied at rates less than the theoretical crop water requirement. This, in agreement with Mierau (1974), is true for effective rainfall as predicted by either the SCS effective rainfall formula in (9 of 10) dry seasons or total rainfall effective assumption in (6 of 10) dry seasons.

2. During the 1971-1987 dry seasons with above normal rainfall, assuming total rainfall being effective, applied irrigation was generally greater in (6 of 7) dry seasons than the theoretical crop water requirement. Mierau (1974) assumed total rainfall as effective rainfall, and reported a similar trend. By applicatioon of the SCS effective rainfall formula, applied irrigation was less than the theoretical crop water requirement during all of the 1971-1987 dry seasons with above normal rainfall.

3. During the 1971-1987 dry seasons, irrigators in the EAA study area have generally applied less irrigation than the amount allowable under present water use permitting criteria. Mierau (1974) reported that the maximum application withdrawal rate was substantially below that allowed by the water use permitting criteria in effect at that time. Currently the Regulation Department allocates

irrigation water for agricultural users based on the irrigation system efficiency, the estimated crop water requirement, and the effective rainfall estimated by the SCS effective rainfall formula. The present study found that the applied irrigation was less than the theoretical requirement in 16 of 17 dry seasons when the SCS effective rainfall formula was used.

4. Prior to implementation of the IAP in 1979, annual pumped volumes from the EAA to Lake Okeechobee were approximately equal to the annual irrigation releases from Lake Okeechobee to the EAA. Mierau (1974) found a similar trend during 1962-1971. Since 1979, in an effort to reduce nutrient loads to Lake Okeechobee, additional drainage water from the EAA was pumped to the WCAs. Because of this, the annual pumped volume to Lake Okeechobee is less than the annual irrigation release to the EAA.

REFERENCES

Biswas, B. C. 1988. Agroclimatology of the Sugar-Cane Crop. Technical Note No. 193. World Meteorological Organization. Geneva, Switzerland.

Central and Southern Florida Flood Control District. 1975. Summary of the Condition of South Florida Water Storage Areas in the 1974-1975 Dry Season.

CH2M-Hill. 1978. Water Quality Studies in the Everglades Agricultural Area of Florida. Report submitted to the Florida Sugar Cane League.

Dastane, N.G. 1974. Effective Rainfall in Irrigated Agriculture. FAO Irrigation and Drainage Paper 25. Food and Agriculture Organization. Rome.

Doty, J. W. 1964. Pre-Harvest Sampling of Sugarcane for Maturity Determination in Sugarcane Production in Florida, Proceedings of Sugarcane Symposium Twenty-fourth Annual Meeting. Soil and Crop Science Society of Florida. pp 475-482.

Doorenbos, J. and W.O. Pruitt. 1977. Crop Water Requirements. FAO Irrigation and Drainage Paper 24. Food and Agriculture Organization. Rome.

Environmental Quality Division. 1979. Palm Beach County 208 Areawide Waste Treatment Management Plan. Area Planning Board of Palm Beach County. pp. 3.10-3 - 3.10-14

Fan, Andrew and Raymond Burgess. 1983. Surface Water Availability of the Caloosahatchee Basin. South Florida Water Management District.

Florida Agricultural Statistics Service. Field Crops Summary. Bulletins from 1975-1987.

Florida Agricultural Statistics Service. Vegetable Summary. Bulletins from 1975 - 1987.

Florida Agricultural Statistics Service. 1980. Vegetable Preliminary Summary. 1979-1980 Planted Acreage.

Florida Sugar Cane League. 1988. Florida Sugar Industry Production 1967 - 1987. 1 pg.

Izuno, F. T. and J. Alvarez. 1987. Sugarcane Growth Characteristics Under Natural Water Table Conditions in South Florida. Completion Report for the "Use Development Effort" of the Project Entitled "Crop Water Response and Economic Impact Modeling of Sugar Cane in South Florida". EREC. Belle Glade, Florida.

Jones, J. W., L. H. Allen, S. F. Shih, J. S. Rogers, L. C. Hammond, A. G. Smajstrla, and J. D.Martsolf. 1984. Estimated and Measured Evapotranspiration for Florida Climate, Crops, and Soils. Institute of Food and Agricultural Sciences Bulletin 840. Gainesville, Florida.

Lin, Steve, Jim Lane and Jorge Marban. 1984. Meteorological and Hydrological Analysis of the 1980-1982 Drought. South Florida Water Management District.

Lin, Steve and Richard Gregg. 1988. Water Budget Analysis Water Conservation Area 1. South Florida Water Management District.

Mierau, Ronald. 1974. Supplemental Water Use in the Everglades Agricultural Area. Central and Southern Florida Flood Control District.

Pearson, Larry. 1988. Lake Okeechobee Service Area Agricultural Demand Analysis. Memorandum to Jorge Marban. South Florida Water Management District.

Resource Control Department. 1985. Management of Water Use. Permit Information Manual Volume III. South Florida Water Management District.

Sculley, Shawn. 1986. Frequency Analysis of SFWMD Rainfall. South Florida Water Management District.

Shih, S. F., L. H. Allen, Jr., L. C. Hammont, J. W. Jones, J. S. Rogers and A. G. Snajstrla. 1983. Basinwide Water Requirement Estimation in Southern Florida. Transactions of the ASAE. Vol. 26, No. 3, pp. 760-766.

Shih, S. F. 1984. Impact of Water Cutback on Sugarcane Production in the Florida Everglades. Water Resources Bulletin. Vol. 20, No. 2, pp. 187-191.

South Florida Water Management District. 1981. Operations Report. May, June, July.

South Florida Water Management District. 1985. A Closer Look: Lake Okeechobee Backpumping.

USDA Soil Conservation Service. 1967. Revised 1970. Irrigation Water Requirements. Technical Release No. 21.

APPENDIX

TABLE A1. Required and Applied Irrigation

Year	Month	Required Irrigation		Applied Irrigation	
		SCS Effective Rainfall (Inches)	Total Rainfall Effective (Inches)	Acre-feet	Inches
70	1	0.0	0.0	14999	0.4
70	2	0.6	0.0	8255	0.2
70	3	0.0	0.0	4982	0.1
70	4	4.2	4.1	56035	1.7
70	5	0.7	0.0	104932	3.1
70	6			3491	0.1
70	7			2126	0.1
70	8			1244	0.0
70	9			10772	0.3
70	10			32071	1.0
70	11	2.5	2.4	68807	2.1
70	12	1.7	1.6	76088	2.3
71	1	1.5	1.3	48494	1.4
71	2	1.3	0.8	22828	0.7
71	3	3.5	3.4	63233	1.8
71	4	4.6	4.5	82608	2.4
71	5	2.3	0.8	29457	0.9
71	6			8773	0.3
71	7			401	0.0
71	8			2315	0.1
71	9			0	0.0
71	10			8920	0.3
71	11	0.2	0.0	24496	0.7
71	12	1.2	0.8	36676	1.1
72	1	1.1	0.7	23409	0.6
72	2	1.1	0.5	21870	0.6
72	3	1.3	0.3	46848	1.2
72	4	0.0	0.0	29889	0.8
72	5	0.4	0.0	1783	0.0
72	6			3600	0.1
72	7			12752	0.3
72	8			21326	0.6
72	9			9396	0.2
72	10			69552	1.8
72	11	0.3	0.0	26579	0.7
72	12	0.6	0.0	21455	0.6
73	1	0.3	0.0	8095	0.2
73	2	1.1	0.8	4550	0.1
73	3	1.4	0.5	23165	0.6

TABLE A1. Required and Applied Irrigation

Year	Month	Required Irrigation		Applied Irrigation	
		SCS Effective Rainfall (Inches)	Total Rainfall Effective (Inches)	Acre-feet	Inches
73	4	3.7	3.5	78825	2.1
73	5	2.2	0.8	79498	2.1
73	6			17006	0.4
73	7			1146	0.0
73	8			20	0.0
73	9			863	0.0
73	10			28140	0.7
73	11	2.2	2.0	111414	2.9
73	12	0.6	0.0	41062	1.1
74	1	1.0	0.6	7981	0.2
74	2	2.4	2.2	49896	1.3
74	3	2.9	2.7	71964	1.9
74	4	3.0	2.7	79289	2.1
74	5	2.0	0.7	71806	1.9
74	6			7936	0.2
74	7			1388	0.0
74	8			0	0.0
74	9			0	0.0
74	10			23425	0.6
74	11	0.8	0.1	86916	2.3
74	12	0.9	0.5	33923	0.9
75	1	1.8	1.7	48417	1.3
75	2	1.7	1.4	65078	1.7
75	3	2.6	2.4	103111	2.8
75	4	2.9	2.6	143096	3.8
75	5	0.4	0.0	53447	1.4
75	6			3094	0.1
75	7			0	0.0
75	8			833	0.0
75	9			2	0.0
75	10			1182	0.0
75	11	1.5	1.1	31371	0.8
75	12	1.8	1.7	77213	2.1
76	1	1.5	1.2	40019	1.1
76	2	0.1	0.0	34096	0.9
76	3	2.5	2.2	29580	0.8
76	4	3.0	2.7	92273	2.5
76	5	0.0	0.0	12569	0.3
76	6			10	0.0

TABLE A1. Required and Applied Irrigation

Year	Month	Required Irrigation		Applied Irrigation	
		SCS Effective Rainfall (Inches)	Total Rainfall Effective (Inches)	Acre-feet	Inches
76	7			1380	0.0
76	8			0	0.0
76	9			0	0.0
76	10			56291	1.5
76	11	1.1	0.5	55505	1.5
76	12	0.4	0.0	24474	0.7
77	1	0.0	0.0	5314	0.1
77	2	1.7	1.5	17088	0.5
77	3	3.1	2.9	69037	1.9
77	4	3.8	3.7	103103	2.8
77	5	0.6	0.0	41599	1.1
77	6			21777	0.6
77	7			9854	0.3
77	8			6486	0.2
77	9			565	0.0
77	10			46522	1.3
77	11	0.0	0.0	19660	0.5
77	12	0.0	0.0	456	0.0
78	1	0.2	0.0	1027	0.0
78	2	0.8	0.2	8229	0.2
78	3	1.7	1.1	21505	0.6
78	4	3.2	2.9	74755	2.1
78	5	1.4	0.0	29538	0.8
78	6			13589	0.4
78	7			315	0.0
78	8			0	0.0
78	9			0	0.0
78	10			3953	0.1
78	11	0.8	0.0	13135	0.4
78	12	0.0	0.0	16334	0.5
79	1	0.0	0.0	12659	0.4
79	2	2.1	2.0	48706	1.4
79	3	2.0	1.5	48641	1.4
79	4	2.3	1.6	79747	2.2
79	5	1.3	0.0	30260	0.8
79	6			153396	4.3
79	7			27092	0.8
79	8			5534	0.2
79	9			0	0.0

TABLE A1. Required and Applied Irrigation

Year	Month	Required Irrigation		Applied Irrigation	
		SCS Effective Rainfall (Inches)	Total Rainfall Effective (Inches)	Acre-feet	Inches
79	10			3227	0.1
79	11	0.1	0.0	585	0.0
79	12	0.5	0.0	6141	0.2
80	1	0.0	0.0	33078	0.9
80	2	1.0	0.5	4774	0.1
80	3	1.7	0.9	16419	0.5
80	4	1.1	0.0	7035	0.2
80	5	1.7	0.0	54002	1.5
80	6			93646	2.6
80	7			27832	0.8
80	8			8069	0.2
80	9			0	0.0
80	10			38100	1.1
80	11	0.9	0.1	16602	0.5
80	12	1.4	1.1	18559	0.5
81	1	1.8	1.6	33562	0.9
81	2	0.9	0.0	11508	0.3
81	3	2.8	2.5	36799	1.0
81	4	4.3	4.2	102391	2.8
81	5	3.0	2.0	81348	2.3
81	6			44822	1.2
81	7			49547	1.4
81	8			4776	0.1
81	9			2719	0.1
81	10			28159	0.8
81	11	0.4	0.0	19154	0.5
81	12	2.6	2.5	38245	1.1
82	1	1.9	1.7	17950	0.5
82	2	1.0	0.3	10360	0.3
82	3	0.1	0.0	14214	0.4
82	4	1.9	1.0	43734	1.2
82	5	0.0	0.0	65889	1.8
82	6			7749	0.2
82	7			0	0.0
82	8			2614	0.1
82	9			0	0.0
82	10			11476	0.3
82	11	2.0	1.7	14339	0.4
82	12	1.9	1.7	29111	0.8

TABLE A1. Required and Applied Irrigation

Year	Month	Required Irrigation		Applied Irrigation	
		SCS Effective Rainfall (Inches)	Total Rainfall Effective (Inches)	Acre-feet	Inches
83	1	0.0	0.0	13343	0.4
83	2	0.0	0.0	0	0.0
83	3	0.4	0.0	0	0.0
83	4	3.2	2.8	24895	0.7
83	5	4.6	4.2	132333	3.6
83	6			101	0.0
83	7			23302	0.6
83	8			89	0.0
83	9			8194	0.2
83	10			3402	0.1
83	11	1.9	1.5	15451	0.4
83	12	0.0	0.0	15029	0.4
84	1	2.0	1.9	14876	0.4
84	2	1.5	1.0	38688	1.1
84	3	1.4	0.1	50249	1.4
84	4	2.8	2.1	59802	1.6
84	5	0.9	0.0	111943	3.1
84	6			47361	1.3
84	7			0	0.0
84	8			13238	0.4
84	9			28433	0.8
84	10			49484	1.4
84	11	1.0	0.0	54740	1.5
84	12	2.3	2.2	41865	1.1
85	1	1.8	1.6	53306	1.5
85	2	2.6	2.5	53474	1.5
85	3	2.1	1.5	67490	1.8
85	4	0.8	0.0	29889	0.8
85	5	3.6	2.9	84222	2.3
85	6			79281	2.2
85	7			2858	0.1
85	8			0	0.0
85	9			0	0.0
85	10			5693	0.2
85	11	2.1	1.7	13960	0.4
85	12	0.9	0.3	14481	0.4
86	1	0.5	0.0	11861	0.3
86	2	1.7	1.3	8660	0.2
86	3	0.5	0.0	2987	0.1

TABLE A1. Required and Applied Irrigation

Year	Month	Required Irrigation		Applied Irrigation	
		SCS Effective Rainfall (Inches)	Total Rainfall Effective (Inches)	Acre-feet	Inches
86	4	4.8	4.7	64169	1.7
86	5	2.9	1.9	79569	2.2
86	6			12407	0.3
86	7			760	0.0
86	8			0	0.0
86	9			2824	0.1
86	10			13916	0.4
86	11	1.7	1.2	12236	0.3
86	12	0.0	0.0	30091	0.8
87	1	1.1	0.7	8630	0.2
87	2	1.4	1.0	7837	0.2
87	3	0.0	0.0	4742	0.1
87	4	4.5	4.4	61533	1.7
87	5	3.4	2.7	79734	2.2
87	6			121258	3.3
87	7			4665	0.1
87	8			23518	0.6
87	9			5861	0.2
87	10			6605	0.2
87	11	0.0	0.0	0	0.0
87	12	1.8	1.7	10675	0.3